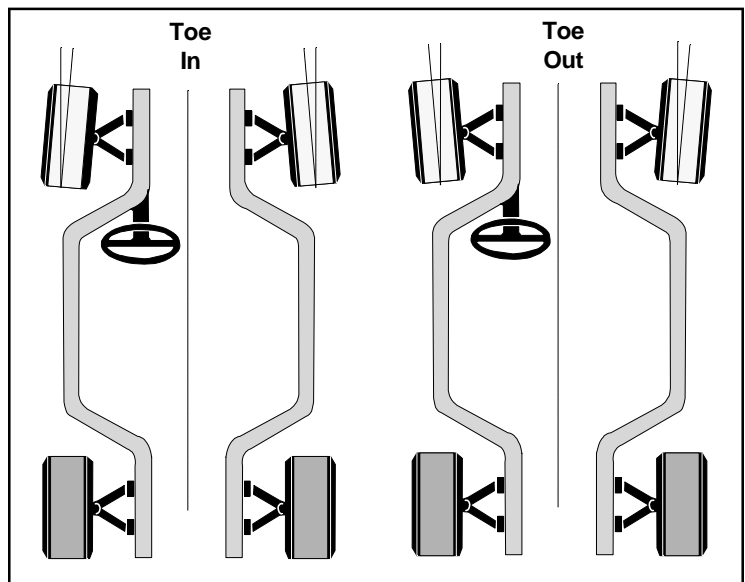
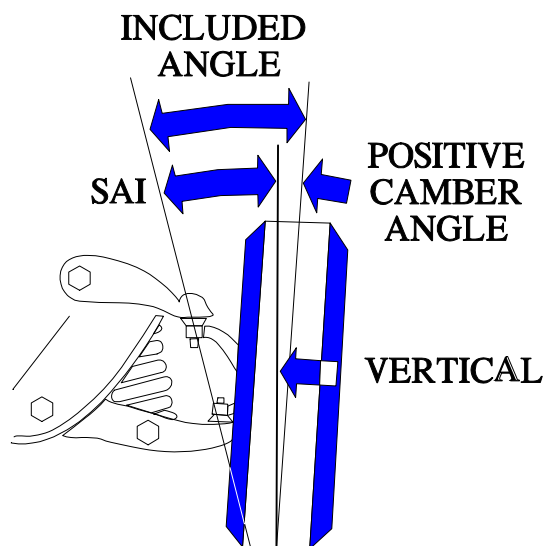




Fundamentals of Suspension & 4-Wheel Alignment

Interactive Multimedia Edition



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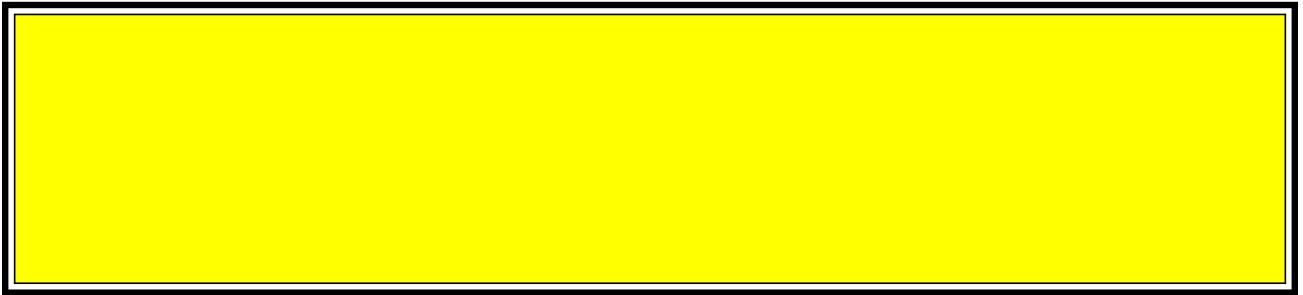


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Welcome to the

Alignment Theory Workbook

This manual is designed to give you a solid foundation from which you can further your career in the ever-changing field of Automotive Alignment. It is not, however, designed to be a “Teach Everything That There Is To Know” manual. Instead, each chapter will deal with the basic information about either a part of the car or an alignment angle, what it does, and what can happen if it is worn, damaged, or incorrectly adjusted.

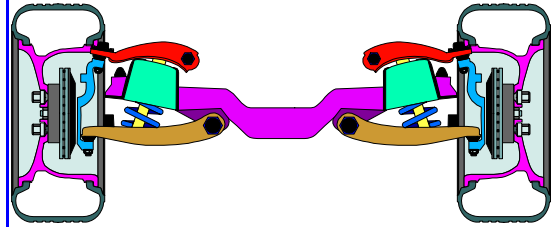
Whenever possible, it is recommended that you have access to a vehicle with a suspension or steering linkage system similar to the one discussed in the section you are currently reading. This way, you can not only read about and see pictures of different systems, but you can observe, first-hand, the actual parts, where they are located, and how they move or act when the vehicle is bounced or in motion. You will notice there is a space for your own personal notes on each page. After looking at a vehicle and seeing the part or parts being studied, you may find something in particular strikes your eye or looks different than described. Make notes of these observations in the space. If you have a particular question about what you are seeing or about the text you are reading, make a note.

SPRINGS

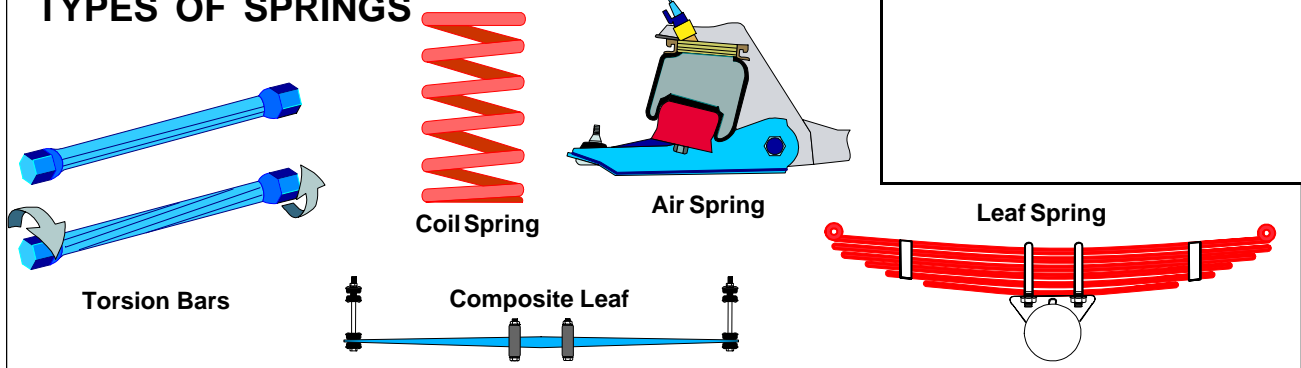
FUNCTION

- * Allows suspension movement for better tire to road contact
- * To maintain correct chassis ride height.
- * To assist in absorbing road shock.

The construction of springs is an elastic material such as steel, rubber, or plastic. The spring uses the vehicle's weight to push the tire into constant contact with the road. Sir Isaac Newton once observed that, for every action there is an equal and opposite reaction. The opposite reaction to the weight pushing the



TYPES OF SPRINGS



tire onto the road surface is to push up on the vehicle. This is how a spring maintains the correct chassis ride height.

When the tire meets an obstruction on the road, for example a pot hole or bump, it pushes up into the wheel well (**jounce**), or drops down into the road hole (**rebound**). The spring stores tremendous energy during jounce. The spring releases tremendous energy during rebound. This storing and releasing of energy causes the spring to "**oscillate**" or bounce several times until releasing all excess energy. While this oscillation is occurring, the tire will change its relative position to the road surface, causing a scrubbing of the tire tread, as well as handling problems for the driver.

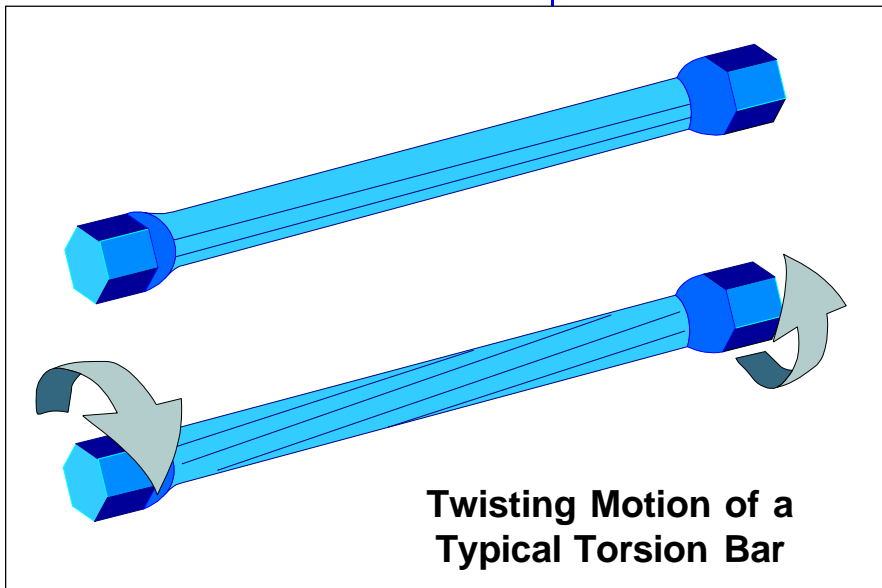
All of this work causes the spring to weaken. As it weakens, it can no longer hold the vehicle weight as well. It cannot keep the tire as firmly planted on the road. As it weakens, it also causes undue forces on other suspension parts, causing them to wear out prematurely. *Never heat springs to alter a vehicle's suspension height.*

These springs come in several different designs:

TORSION BARS

The torsion bar is simply a round bar of steel that is capable of being twisted and storing energy. One end

of the torsion bar is anchored to the frame of the vehicle. The other end is anchored to one of the control arms. As jounce and/or rebound occurs, the torsion bar is twisted more or less. The elasticity of the spring steel tries to return the bar to its normal position, thus dissipating the energy stored during the twisting of the bar.



Vehicles are designed to use either **Longitudinal** torsion bars, (parallel to the sides of the vehicle), or

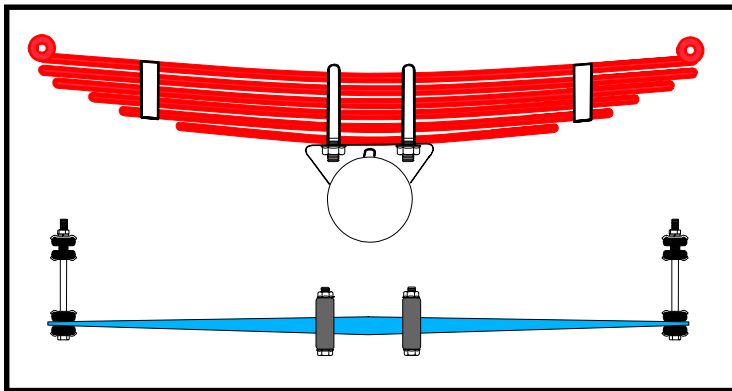
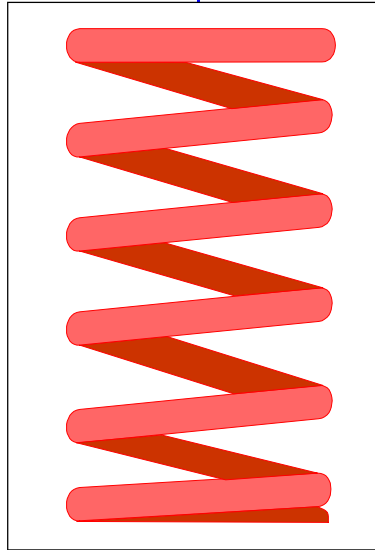
transverse torsion bars, (across the car from side to side). In both designs, there is usually an adjusting bolt or nut at one end of the torsion bar. This adjustment restores the correct ride height when the torsion bars begin to weaken. **Check and adjust torsion bars before performing an alignment.**

COIL SPRINGS

A coil spring is nothing more than a torsion bar wrapped around a cylinder into a coil shape. As they move up and down during jounce and rebound, the bar of spring steel is actually twisting.

As it twists, it gets shorter and then longer as it untwists, or unwinds.

This is why you always see a broken spring come to a point. With both torsion bars and coil springs, the twist is throughout the steel. Deep nicks or scores on the metal surface weaken the spring at that point. Then, during the jounce cycle, a break occurs. The break starts at the point where the nick or score mark is and continuing around the bar until it breaks completely.



Coil spring suspensions do not have any method for adjustment to compensate for weakened springs. **Replace coil springs in pairs when worn or sagged.**

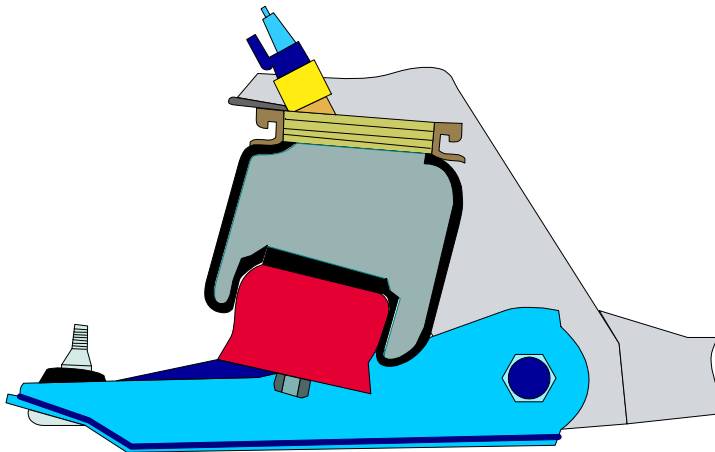
Coil springs are often identified by spring rate. Spring rate is the amount of weight, in pounds, it would take to compress a coil spring one inch.

LEAF SPRINGS

Leaf springs are usually constructed of spring steel. However, some manufacturers use fiberglass-reinforced plastic (FRP) for these springs, such as the Corvette and Chevy Astro van. These springs are made in the form of flat slats, or leaves, that generally have a slight curvature to them. The amount of curvature is called the spring **ARCH**. As jounce and rebound occur, the spring leaf tends to flatten out from its arch and then return to its original shape. Leaf springs are designed with three point attachments, (one at each end to the frame, a third to the axle). Leaf springs hold the axle in its correct alignment to the frame. A center bolt passing through the spring and resting in a locating hole in the axle spring seat assures axle to spring alignment.

AIR SPRINGS

Typical Air Spring Cutaway



The air spring is a rubber bag filled with air. In most applications, an air spring will provide a softer ride than conventional springs. If a force is applied that compresses the air it will shorten the air spring. As the air returns to its original state it will lengthen the air spring, therefore acting like a conventional spring. ***Many systems are controlled by an on-board computer and must be***

switched off before alignment is performed.

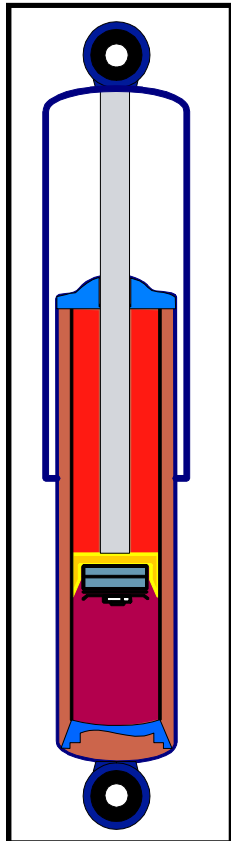
Take precautions when jacking or hoisting vehicles equipped with air suspension systems. If an air spring is extended without adequate air pressure, the walls of the air spring can collapse inward over

the piston. Without air in the spring, damage to the spring can occur when the control arm moves upward.

Most vehicles equipped with air spring suspension systems have ride height sensors which can be adjusted a small amount to correct ride height.

Consult vehicle service manuals for more details on these systems.

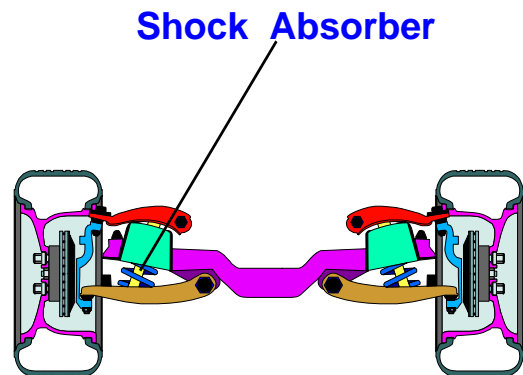
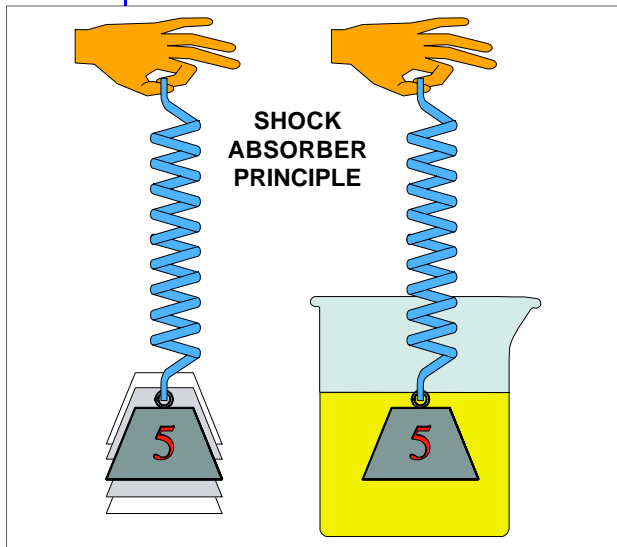
SHOCK ABSORBERS



Earlier, we talked about the oscillations that a spring goes through while storing and releasing energy. This oscillation, if allowed to go unchecked, would cause serious handling problems for the driver, as well as braking problems and tire wear. Therefore, each spring is equipped with a spring oscillation dampening device (shock absorber).

If we simply dropped a weight attached to a spring, the weight would move up and down until the energy dissipates within the spring. *What do you think would happen if we dropped the same weight, attached to the same spring, into a glass of oil?* What if the weight had big holes in it? Smaller holes? Still

smaller holes? The holes would allow some of the oil to pass through the weight, cushioning its impact with the oil. This is the principle of the basic shock absorber. The piston end is attached to the frame of the

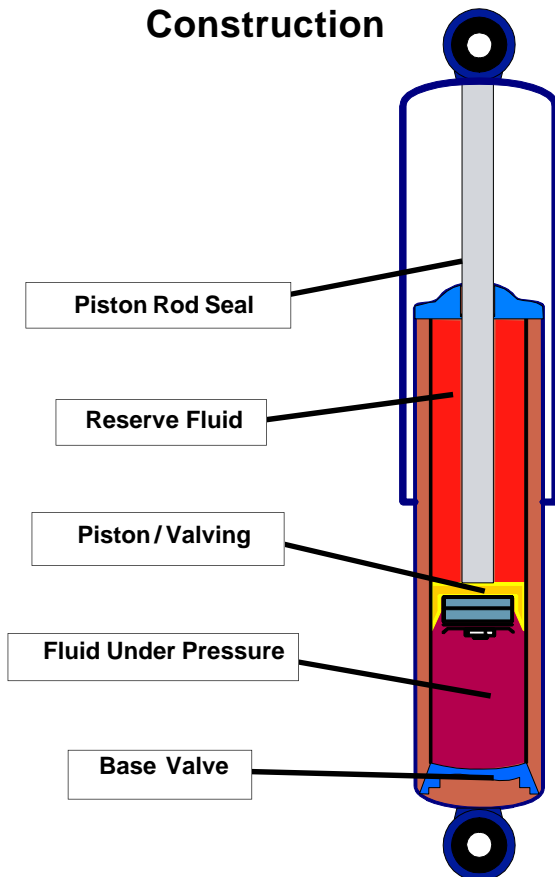


vehicle. The cylinder end is attached to the axle or control arm. When the wheels meet a bump, the cylinder is pushed upwards. The cylinder is a sealed, oil filled container whose inside diameter is the same as the outside diameter of the piston valve. As the cylinder pushes upwards, oil is pushed through the holes in the piston valve. The size of the holes and the thickness (viscosity) of the oil determines how much cushioning or resistance to movement the shock has. This way, the shock absorber takes much of the strain away from the spring by dissipating some of the energy through its cushioning effect. Stiffer shocks or heavy duty shocks will provide a firmer ride. The firmer ride will result in less suspension movement. Heavy duty shocks could be needed for high performance vehicles or vehicles carrying heavy loads or frequent travel over rough roads. Shock absorbers do not affect ride height unless it is a spring assisted or air assisted type.

Many shock absorbers are "Gas Filled" for improved consistency and longer life. Gas filled shocks are charged with nitrogen gas which decreases aeration (foaming) of the oil inside the shock.

Because of its job duties, check the shock absorber for any broken mounts, deteriorated bushings, or leakage around the piston seal. In addition, perform a bounce test. Bounce each corner of the car several times and then watch that corner after you release it. It should not bounce more than two and one-half times. Be careful not to use just the bounce test to condemn the shock. A weakened or broken spring causes the vehicle to bounce excessively. Also inspect the tire for a scalloped or cupping appearance. This could indicate that the shock or spring is bad, allowing the tire to leave the road and then slam down again.

Shock Absorber Construction



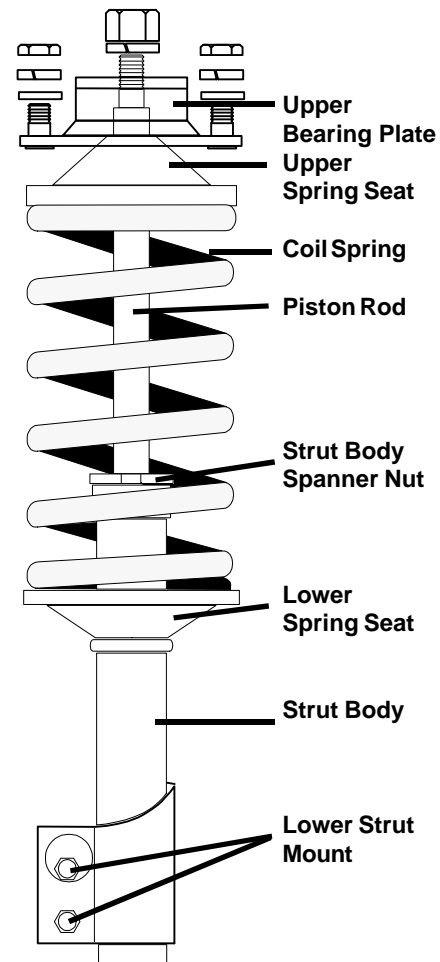
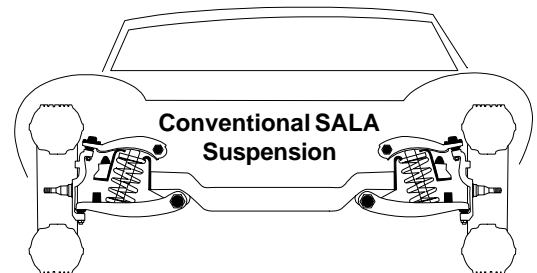
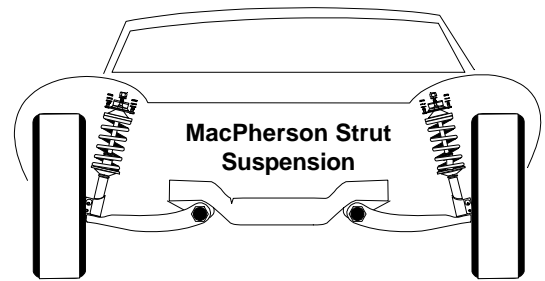
MacPherson Strut

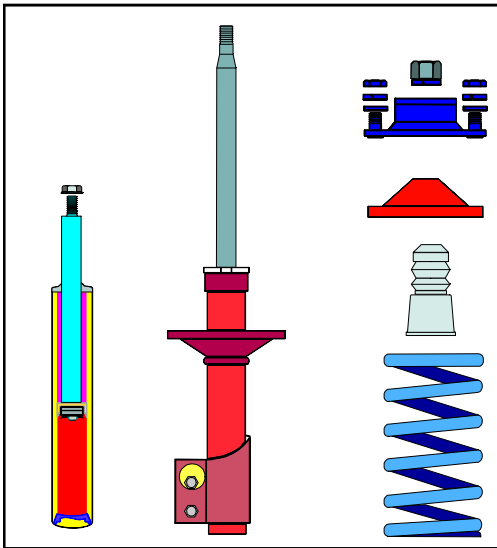
In the late 1940's, a clever engineer thought up a new way to get the same steering geometry as a conventional upper and lower control arm system, but using fewer parts. Additionally, he found that his design could spread suspension loads to the body over a wider span. The road shock could get to the spring without having first to go through a control arm. All of these characteristics made for a more comfortable ride and safer handling. This design had one shortcoming; it had to have the upper portion of the frame and fender well reinforced. Because of that, domestic car manufacturers decided not to adopt his design. So, Earle S. MacPherson took his design to Ford of England, where the MacPherson strut suspension made its debut in 1950.

The MacPherson strut is a unitized design that incorporates the spring, shock absorber, upper control arm, and upper bearing plate all in one unit. The upper bearing plate functions the same as the upper ball joint in the conventional SALA Suspension system. By its design, any road shock is transferred directly from the tire to the spring, without having to pass through a control arm, thus producing a smoother ride. By placing the load point of the spring up higher, and increasing the width between the springs, this design also gives excellent anti-roll characteristics. By using fewer parts, the MacPherson strut also takes up less space, thus creating more room for the engine, and any related accessories like air conditioning and power steering.

The top of the strut is mounted in a rubber and metal assembly, called the **upper strut mount**. Although designs differ somewhat from car to car, basically the mount will have a bearing assembly, guide sleeve for the strut piston rod, and a rubber isolator pad. The strut itself is designed much like a shock absorber, with a piston rod, piston valve, and an oil chamber. If the strut is "rebuildable", there will also be a centering collar for the piston rod. The top of the piston rod is threaded, and passes through the upper strut mount, where it is

Personal Notes





retained by washers and a nut.

Just below the mount is the upper spring seat (sometimes part of the mount). The top of the spring rests in this seat. There is usually an indicator notch to show where the end of the spring should be. Welded to the strut body is the lower spring seat, also with an indicator notch. The spring is held between these two seats with tremendous pressure. Because of this, never remove the piston rod nut until a spring compressor is installed and holding the springs in place.

The strut may be attached at its lower end in one of two basic ways. It may be bolted to the steering knuckle or it may be bolted directly to the lower ball joint, if the spindle is part of the strut.

There is another strut design called Modified Strut. This design utilizes a spring on the lower control arm that contains a load carrying ball joint. This system is very similar to the SALA suspension in the design of the lower control arm and the spring position. The greatest difference between it and the SALA is that the upper control arm is replaced by the Modified Strut Assembly. The upper bearing plate acts as the upper pivot.

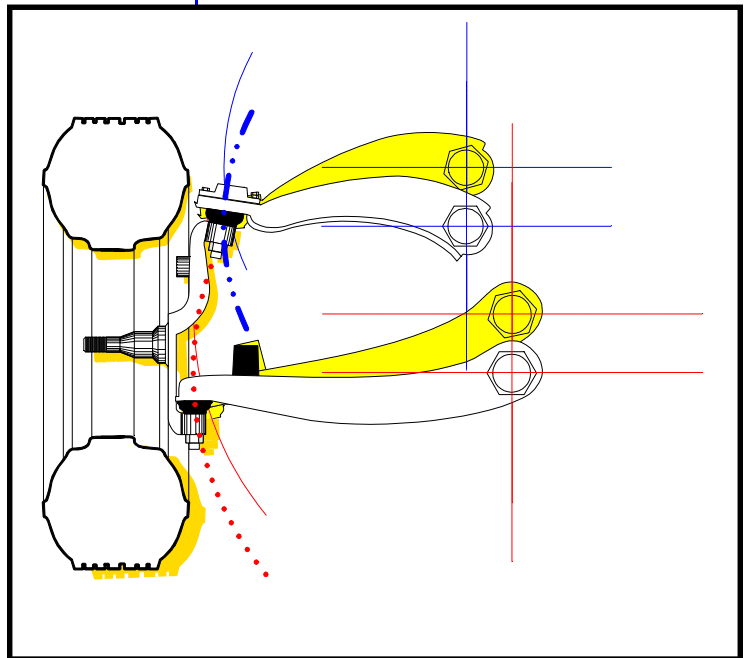
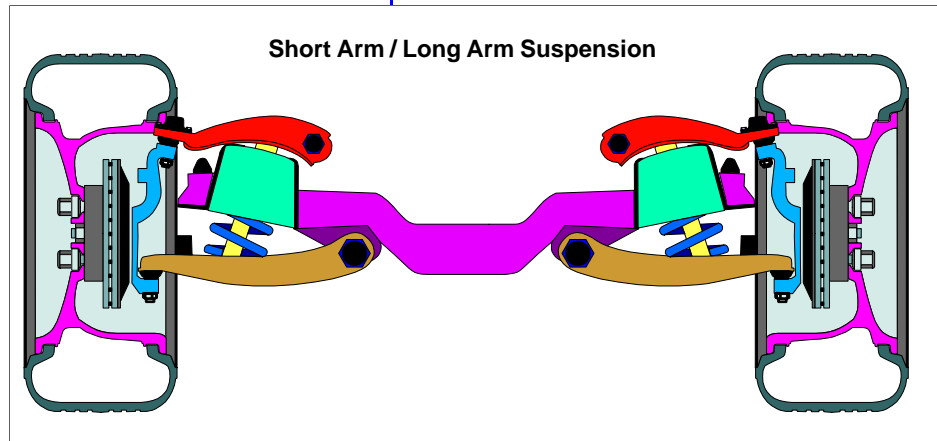
Diagnosis of a MacPherson strut should entail more than just looking to see if the “shock” part is leaking. There is a difference between leakage and seepage. Most struts will seep a little oil through its seal. It is normal to see a light film of oil only at the top of the strut tube. Recommend replacement if the oil film is thick and runs down the side of the tube. Also, if you have alignment equipment attached, raise the car about three inches and lower it by the same amount while watching the camber. If both wheels do not change camber by the same amount, and in the same direction, you probably have a bent strut tube or piston rod. By loosening the piston rod nut (LOOSEN, DO NOT REMOVE!) and rotating the piston rod, you can watch the tire for any camber change. If it is changing, the piston rod is bent; if not, the strut tube is bent.

CONTROL ARMS

As their name implies, control arms control or restrict something. What do they control? **Control arms control the path of travel that the tire can have during jounce and rebound.** The most common arrangement of these control arms is to have a shorter one on top and a larger one on the bottom. This system's name is "**short arm, long arm**" or **SALA** suspension. Because of the difference in their sizes, the control arms move in different arcs during jounce and rebound. The smaller, upper control arm moves in a larger arc and tends to move the top of the tire only.

The larger, lower arm moves in a much smaller arc, and moves the bottom of the tire very little. This way, tire scrubbing is minimized while allowing the chassis to move up and down by a larger amount.

In order for the control arms to move, they must have pivot points. The inner pivot point is attached to the frame with a shaft and bushings. Some vehicles are equipped with two independent shafts (bolts), instead of one single-piece shaft. Regardless of the type, they all use bushings. Most cars and light trucks use a rubber bushing bonded to both inner and outer metal sleeve. The outer sleeve is pressed into the control arm housing, while the inner sleeve is attached, through serrated edges, to the shaft. When the control arm is moved up or down, the outer sleeve is rotated with the arm, while the inner sleeve stays put on the



shaft. This causes the rubber sandwiched between the sleeves to be twisted like a rubber band, thus it tries to un-twist. This bushing, then, acts as a little spring and helps to keep the control arm in its proper position. It also dampens some of the vibrations coming from the tire and wheel assembly.

When inspecting these bushings, check them in their natural position, **with the**

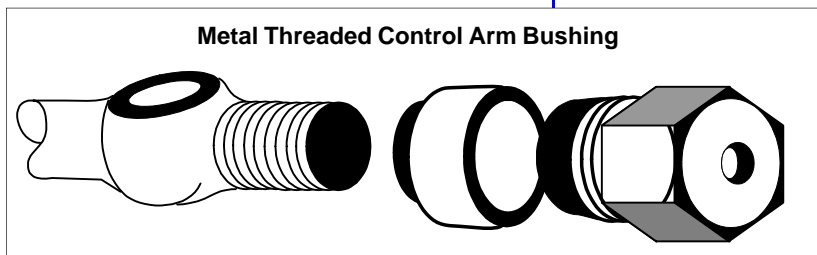
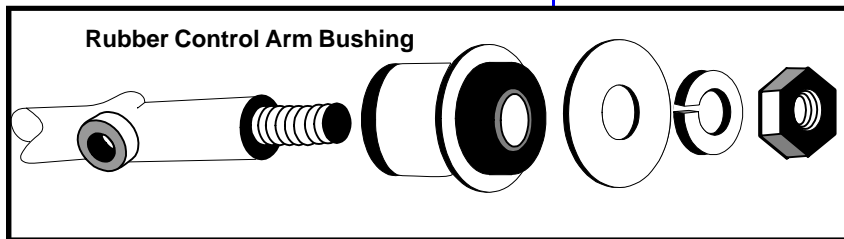
wheels on the ground. Look for obvious deterioration and breakage. Also, make sure the bolt or shaft is going directly through the center of the bushing. If the shaft and bolt are offset from the center, the

bushing has taken a “set” and will not function properly. It may also cause variations in alignment angles when the forces of driving are applied. When replacing these bushings, use a suitable driver or bushing installation tool to install them in the control

arm, and be sure to drive them in straight. Install the bushings at the proper angle to the hole to eliminate damage to the control arm. **DO NOT TIGHTEN THE RETAINING BOLT FULLY UNTIL THE VEHICLE IS IN ITS NORMAL RIDE HEIGHT POSITION.** Failure to do so will cause

the bushing to have a pre-set twist, thus defeating one of its purposes, and leading to premature failure of the new bushings. If you are installing threaded metal bushings, thread each bushing equally onto each end of the shaft. If installed incorrectly, you may have a problem getting the caster angle set. When the bushings reach the bottom of the control arm hole, the pivot shaft should rotate freely in the bushings.

After installing the control arm in the vehicle, lubricate both metal bushings with a hand grease gun.

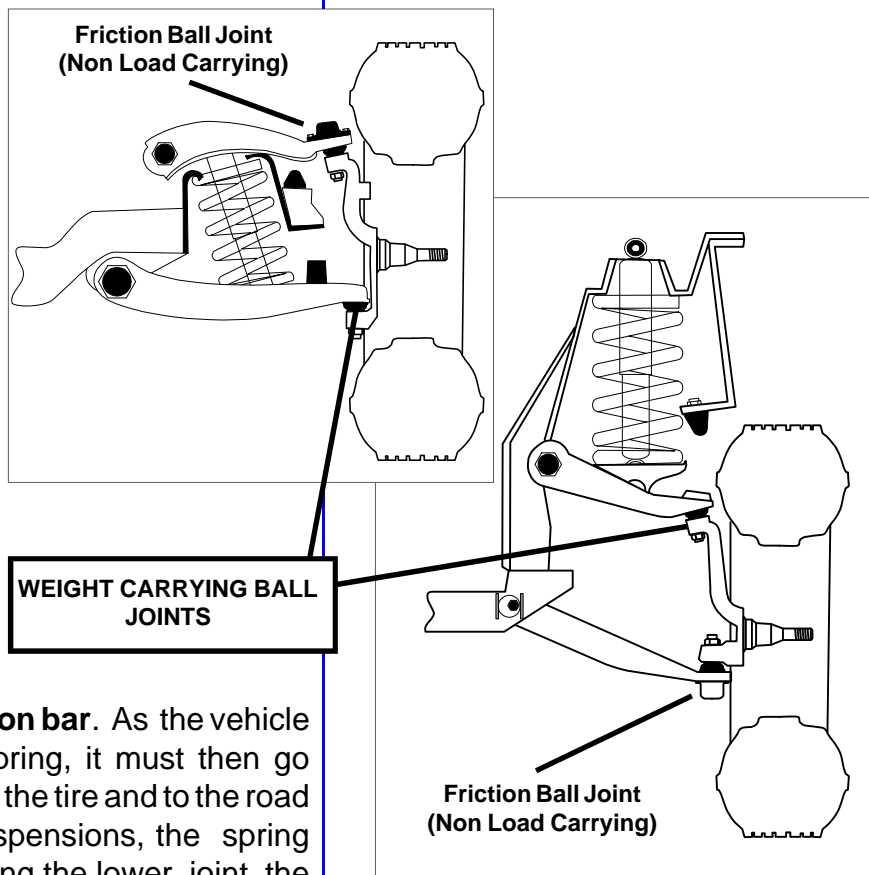


BALL JOINTS

The outside pivot point for the control arm is usually a ball joint. The construction of a ball joint is much like your shoulder joint. **It allows motion in a circular direction and in an arc, but not laterally (in-and-out).** Ball joint construction includes a housing, a ball and tapered seat, a bearing, and some form of pre-load device.

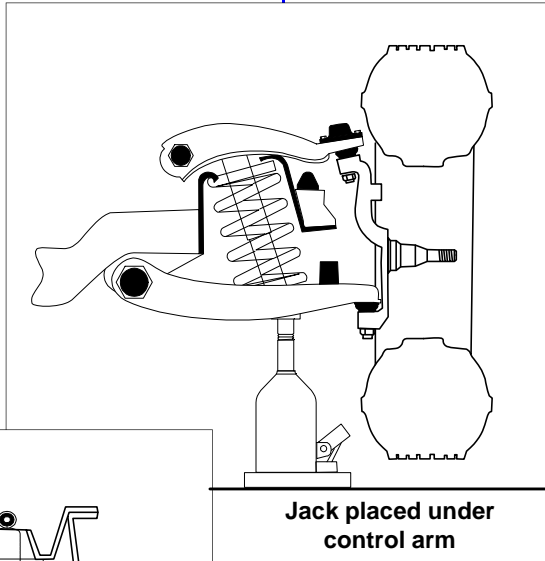
Ball joints come in two basic designs, **compression-loaded** and **tension-loaded**, and are used as either a **weight carrying** pivot or a **friction** pivot. The design of the compression joint allows the weight of the vehicle and the upward push of the tire and steering knuckle to compress the ball stud into the housing. The tension joint is just the opposite, vehicle weight and the push of the tire and knuckle pull the ball stud away from the housing. In either case, the result is to have the ball stud in constant contact with the bearing, which is the wear surface. Most vehicles today use a compression joint for the friction joint and a tension joint for the weight carrying joint.

The location of the weight carrying joint is closest to the seat of the spring or torsion bar. As the vehicle weight passes through the spring, it must then go through this joint to get through the tire and to the road surface. With most SALA suspensions, the spring rests on the lower arm, making the lower joint the weight carrying joint. Some older vehicles, however,

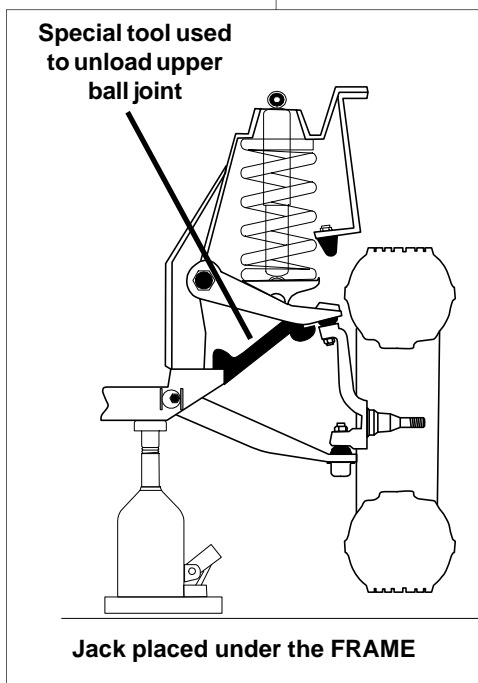


JACK PLACEMENT FOR CHECKING LOAD CARRYING BALL JOINTS

have the spring on the upper control arm, making the upper joint the weight carrying one.



Checking these joints is dependent upon unloading them properly. When the lower joint is the weight carrying joint, jacking under the lower control arm until the tire is clear of the ground will unload it. If the upper joint is the weight carrying joint, you must jack the vehicle up by the frame.



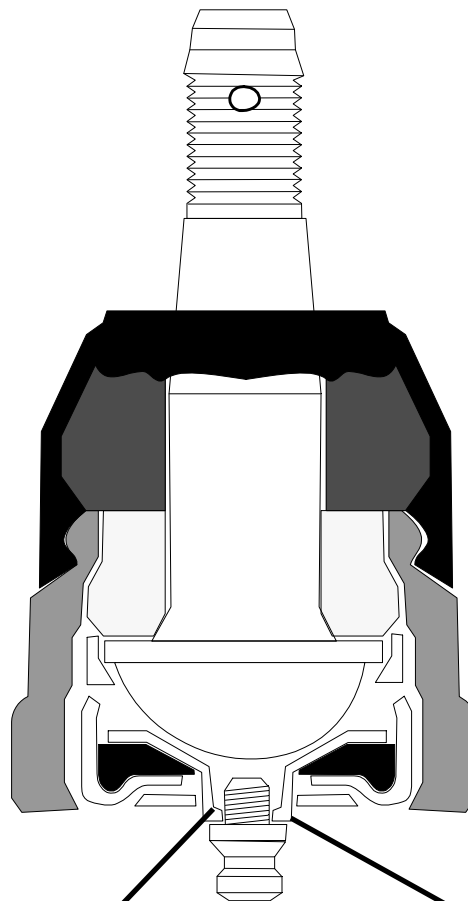
On most cars that have an upper weight carrying joint, there is a travel limiter and/or bump stop to prevent the control arm from hitting the frame during extreme rebound. Use a suitable wedge, available from many alignment tool manufacturers, to hold the control arm away from the frame when checking these joints.

You will find ball joint specifications in the rear of your alignment specs guide. Follow the instructions in the alignment specs guide and use a dial indicator gauge designed for ball joint checking to obtain these readings. Some ball joints may require the use of a torque wrench to check ball joint pre-load.

When checking a friction ball joint, notice in the specs guide that any appreciable movement is beyond the allowable tolerance. Replace the joint if **any appreciable movement** is detected in friction ball joints.

Many ball joints are pressed into the control arm housing. When you buy a replacement ball joint, it is generally about fifty-thousandths (.050) oversized. This is to assure proper ball joint to control arm fit. Replace complete control arms if the ball joint was previously replaced. This is because the first replacement joint stretched the hole in the control arm by .050. The second replacement joint will not fit properly.

Many vehicles are equipped with “**Wear-indicator**” load carrying ball joints. To check these ball joints, the vehicle must be in the “**DRY-PARK**” position, weight on the wheels. The illustration to the left shows a typical wear-indicator ball joint. The location of the indicator is on the bottom plate near the grease fitting. **Replace the ball joint if the indicator is FLUSH with the bottom of the ball joint.** The ball joint is **GOOD** if the indicator is protruding.



WEAR INDICATOR

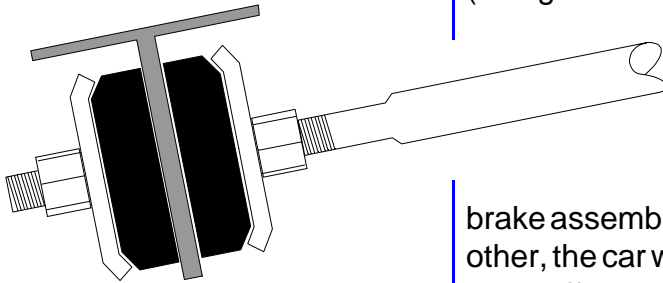
PROTRUDING
INDICATES BALL
JOINT IS *GOOD*

STRUT ROD AND BUSHINGS

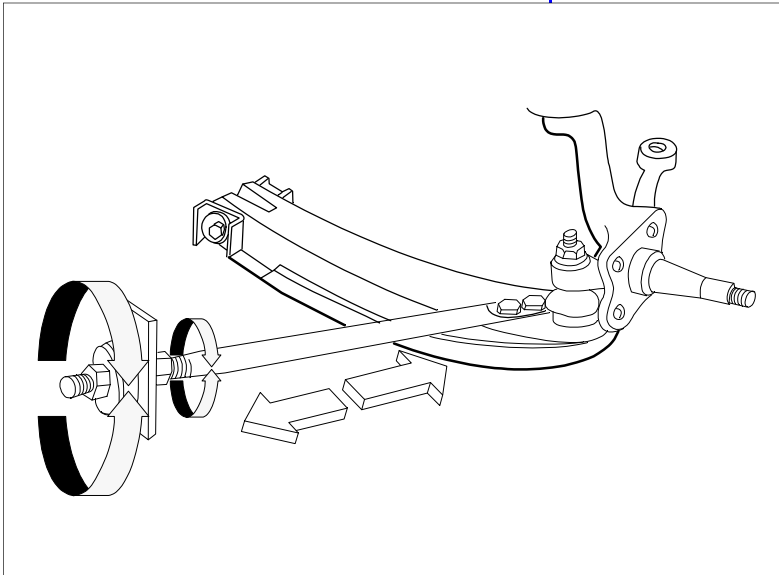
Many vehicles have a lower control arm that looks more like a letter “I” than the traditional letter “A”. The “A” shaped arm uses both legs of the “A” to secure it from any back-and-forth movement. The “I” shaped arm is easily moved back and forth. To prevent this, manufacturer’s design includes a rod attached to the control arm at one end and to the frame at the other end. Bushings attach the frame end. The name of this rod is strut rod, or brake reaction rod. When applying the brakes the ball joint end of the control arm stops (along with the tire) but the frame end wants to

continue moving. If allowed to happen, even slightly, there would be an immediate change in caster, to the negative, which can cause handling problems. If one of the

brake assemblies on the front is more efficient than the other, the car would tend to turn to the side that had the more efficient brake.



Because of this potential for movement, many engineers design the strut rod with threads on the frame end. This way, it is convenient to adjust the caster angle. However, for caster to be accurate at highway speeds and during braking, the mounting bushings must be in good shape. Check them in the “Dry-Park” position for any obvious deterioration, cracking, or breaking. Replace the bushing if the strut rod position is not in the center of the bushing.



STABILIZER BAR

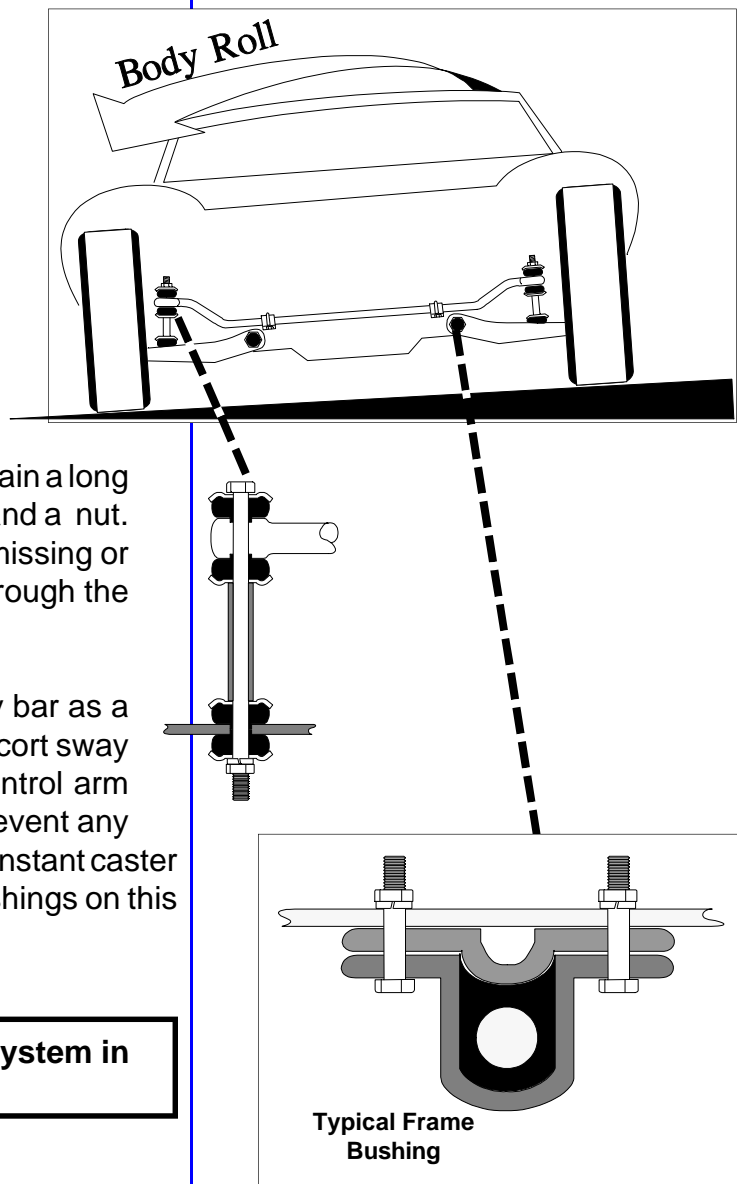
SWAY BAR

When a vehicle goes into a turn, the weight of the vehicle becomes unevenly distributed. This shift causes one side of the car to go downward and the other side to go upward. This weight shift also causes changes in the camber and toe settings, and can result in the driver having to fight the vehicle through the turn.

To minimize the weight shift and resulting height changes during a turn, a spring steel bar is attached across the car to both lower control arms and to the frame. ***The swaybar does not effect ride height when the vehicle is in the straight ahead and level position.*** Swaybar attachment points are through rubber bushings. The frame bushings wrap around the bar, and should be checked for looseness, deterioration, and breakage. The control arm ends of the bar are attached, usually, through link kits. These link kits contain a long bolt, four bushings, washers, a sleeve, and a nut. Check the link kit for bushings that are missing or deteriorated, sleeves that have worn through the washers, or missing washers.

Some manufacturers also use the sway bar as a strut rod also. For example, the Ford Escort sway bar is attached directly to the lower control arm without using a link kit. This helps to prevent any back-and-forth movement of the arm. Constant caster change is the result of worn or loose bushings on this strut rod system.

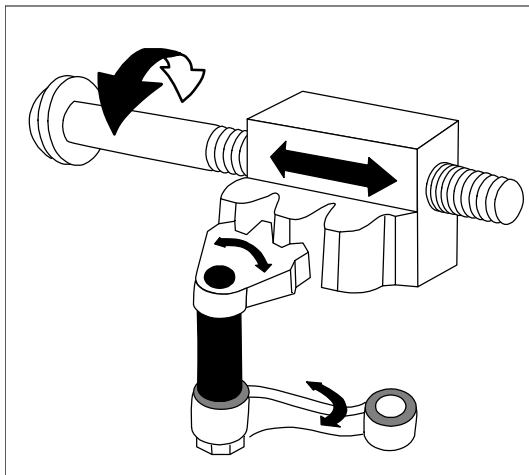
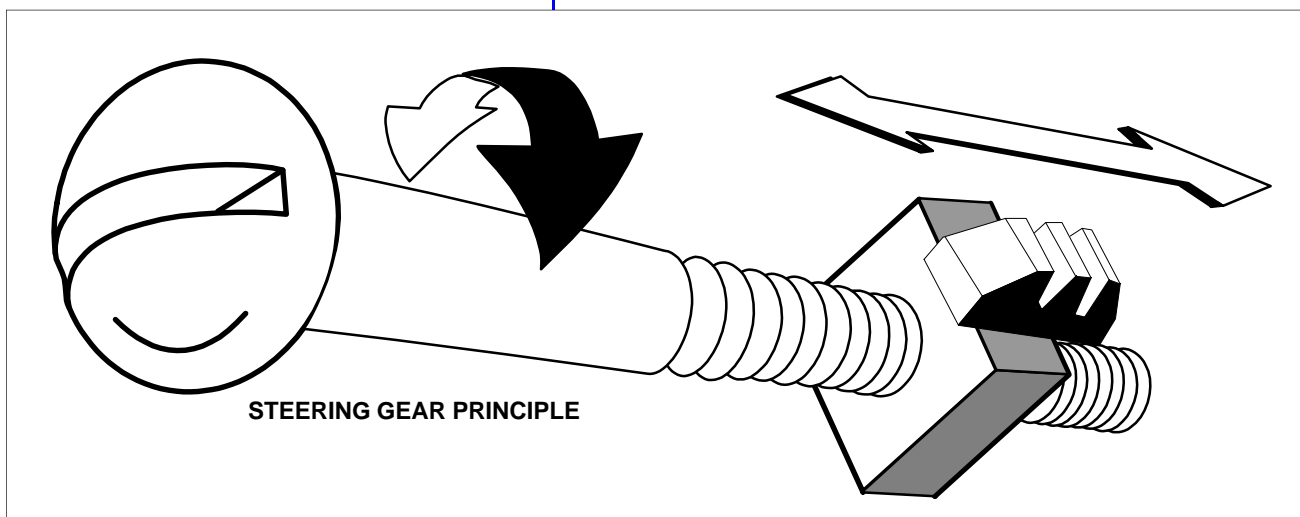
Perform all parts' checks to this system in the "Dry-Park" position.



STEERING SYSTEM

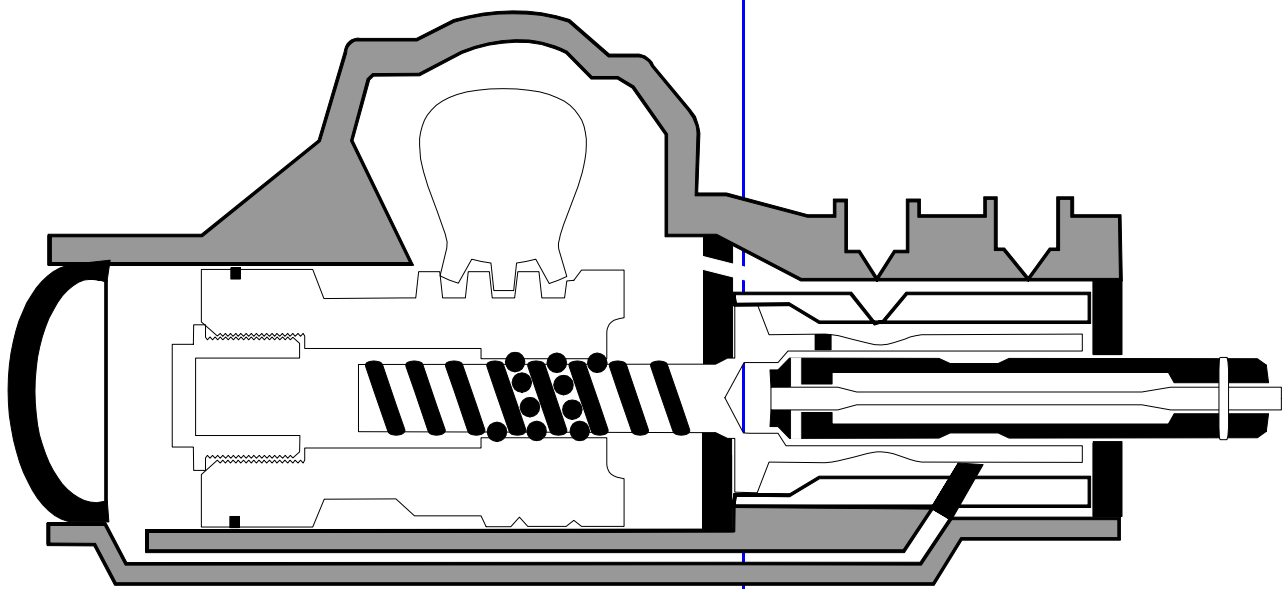
STEERING GEAR

To make the wheels turn, the rotary (around-and-around) motion of the steering wheel is converted into lateral (side-to-side) motion of the steering linkage. A set of gears, called a steering gearbox, is used to accomplish this motion conversion. Until recently, this gear box was usually the “**RECIRCULATING BALL**” type. *Let's take a look at it—*



The basic operation is easy to understand if you simply think of a nut and bolt. Rotate the bolt (the steering wheel and shaft) to the right and the nut is threaded up the bolt. Rotating to the left will make the nut thread down the bolt. If we were to put some gear teeth on the nut and make it mesh with a second gear, we could make the second gear turn by rotating the bolt. In a real gearbox, the bolt is the steering shaft, and is commonly called a worm shaft. It has a very wide-spaced thread on it. The shaft is “threaded” into a nut called a ball nut. Inside the ball nut, instead of threads there are a number of balls that are positioned to roll on the shaft threads. Balls are used because they produce less friction between the moving parts. The balls follow an endless path by means of a ball guide tube which returns the balls to their starting point

when they reach the end of the threads on the shaft. As the steering shaft is rotated by the steering wheel, the ball nut is threaded up or down the shaft. On the side of the ball nut is a gear. This gear is meshed with a second gear, called the sector gear. The sector gear is held in place by the housing, and as the ball nut moves, the meshing of the gears causes the sector gear to rotate. Attached to the bottom of the sector gear is a splined shaft, called the sector shaft. Rotating the steering wheel causes the worm shaft to turn in unison and this causes the ball nut to move. The ball nut moves the sector gear, which rotates the sector shaft.



The steering linkage, which will be described later, is then attached to the sector shaft.

If the vehicle is equipped with power steering, the worm shaft is attached to a spool valve. A spool valve is simply a control gate which directs power steering fluid to the ball nut (power piston) that forces it in one direction or the other.

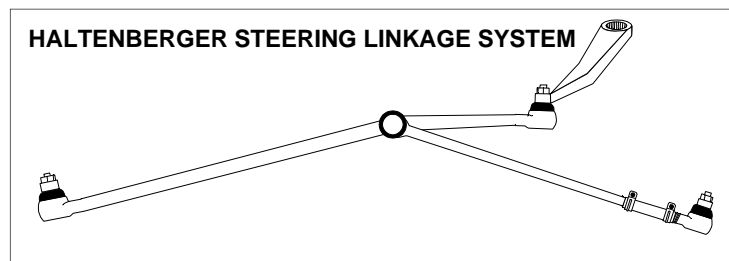
STEERING LINKAGES

Most steering linkages are of one of four types:

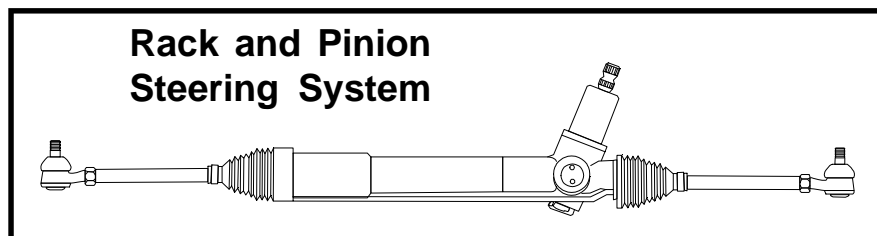
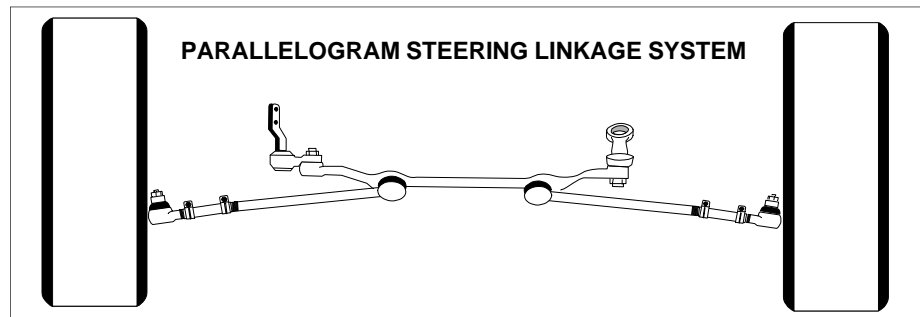
CROSS STEERING...used primarily on four-wheel drive axles



HALTENBERGER...used primarily on Ford Twin-I beam suspensions



PARALLELOGRAM...used on many cars and light trucks

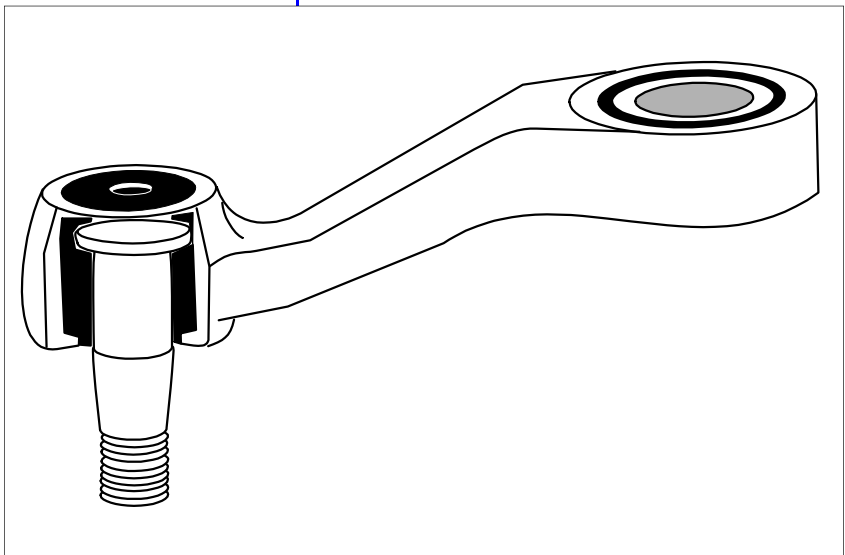
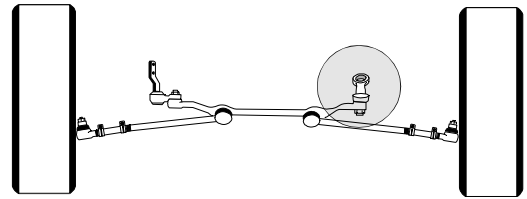


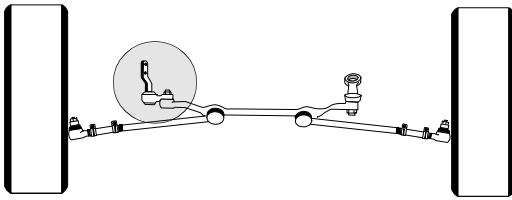
RACK & PINION used on most modern cars & many light trucks.

One of the most common steering systems is the Parallelogram, it contains four main parts; an idler arm, a pitman arm, tie rod ends, and adjusting sleeves. Its name is derived from the fact that the tie rod ends are roughly *parallel to, and about the same length as, the lower control arm*. This is to prevent the tire from going through drastic toe changes during jounce and rebound. The tie rod end and the ball joint both move in similar arcs, so that the tire position can be unchanged during movement.

PITMAN ARM

The **PITMAN ARM** is the first component to be moved by the steering gearbox. The pitman arm stud is the *most heavily stressed joint in the steering system*, since it must move all of the rest of the steering linkage. You can easily check it by having the wheels of the vehicle resting on your rack (locked turntables, if used), and then rocking the steering wheel back and forth. The pitman arm stud, the pitman arm, and the center link should all move as one unit. Replace the pitman arm if you see that the pitman arm is moving but not the stud (at the same time and at the same rate of movement). Look closely, however, at the stud. Is the stud actually a part of the pitman arm, or is it a part of the center link? Many parts catalogs will list "N/A" for the pitman arm. This indicates that the only wearable part (the stud) is on the center link and not the pitman arm.

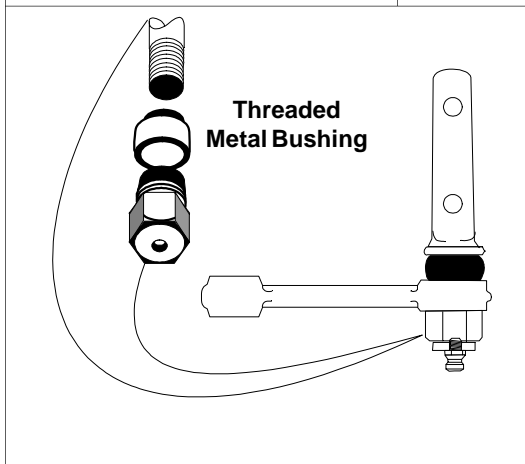
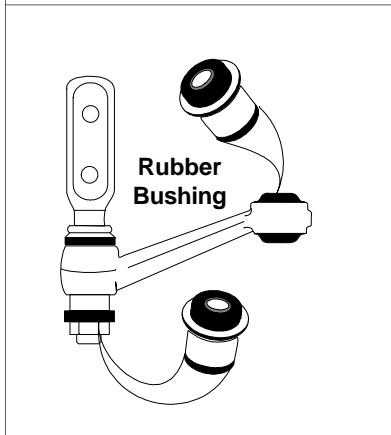
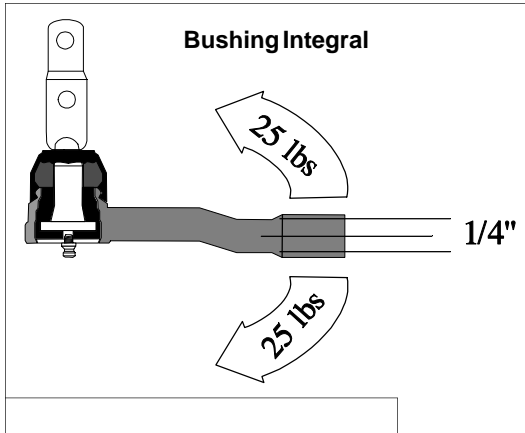




IDLER ARM

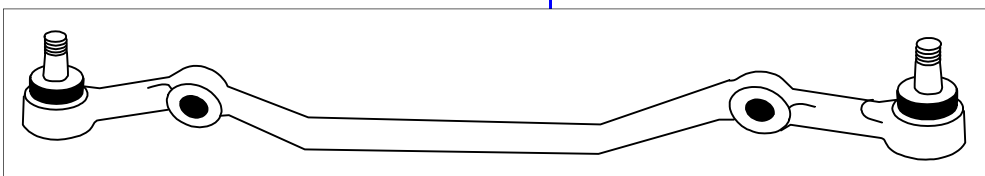
The pitman arm's partner is the **IDLER ARM**. They both *support the center link in its correct horizontal plane*. The idler arm can be one of three basic designs: rubber bushing, integral arm with nylon bushings, or threaded steel bushing. Regardless of its design, the idler arm must not move up or down excessively. If it does, the center link will move out of its horizontal plane and can cause what is referred to as "**bump steer**". The allowable movement in an idler arm is an old argument. Some General Motors service manuals state that when twenty-five pounds of force is exerted on the idler arm at the center link connecting point, the idler arm should not move more than 1/8" in either direction (up or down). Later model GM "F" body products (Camaro and Firebird) have the idler arm mounted to the frame in elongated holes. Adjust it up or down to eliminate bump-steer after the springs have weakened more on one side than the other.

You should remember that the **idler arm**, if excessively loose or worn, ***will cause toe changes while the vehicle is in motion.***



CENTER LINK

The center link is a *bar between the pitman arm and the idler arm*, to which the tie rod ends are attached. Therefore, it is the means of connecting the tires to the steering gear box. It is **designed to travel in a horizontal plane**, pulling one tie rod end with it while pushing the other to make the tires turn. At each end of the center link is either a hole or a stud, for attachment to the idler and pitman arms. Two other holes are about one-fourth of the way in for attaching the tie rod ends. GM "F" body cars (Camaro and Firebird) have a machined flat spot on the center link



at each end. These flat spots are measuring points to establish whether the center link is horizontal or not. If not, then move the idler arm slightly up or down so that both flat spots are within 1/16" of each other.

TIE ROD ENDS

The tie rod ends are much like little ball joints. They allow motion in a circular direction, but not laterally. There are two on each side of the car, the inner and outer tie rod ends. Tie rods are positioned to closely match the travel of the lower control arms. This minimizes the inward and outward movement of the wheels when the suspension travels through jounce and rebound. *The inward and outward movement is **Toe Change**.*

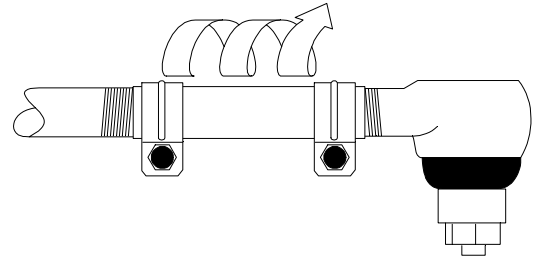
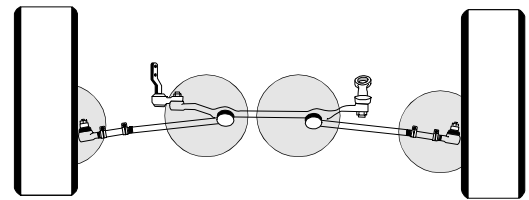
The inner tie rod end is attached to the center link and *allows the wheels to move up and down in relation to the center link*. The outer attaches to the steering arm, which either attaches to the steering knuckle or is a forged part of the knuckle. This allows the tires to turn away (left or right) from the straight ahead position. Both tie rod ends are connected to each other by an **ADJUSTING SLEEVE**. The sleeve is a threaded tube. By turning it, the two tie rods can be moved closer together or farther apart, thus moving the tires inwards or outwards.

Prior to tightening the tie rod sleeve clamps, position the tie rods so the stud is centered in the housing of the tie rod ends.

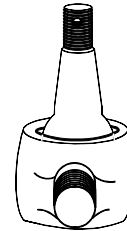
Position the clamps so the split in the clamp is **NO MORE THAN 45 degrees** away from the split in the tie rod sleeve. This will distribute force more evenly around the adjusting sleeve. Do not align the splits of both sleeve and clamp.

Like the pitman arm, the easiest and more accurate method of checking a tie rod socket is by moving the steering wheel back and forth, with the wheels on the rack, and checking the stud for any movement. ***If you see movement, then the toe angle will change as the vehicle moves down the road, causing excessive tire wear.***

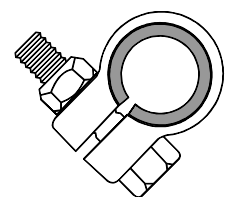
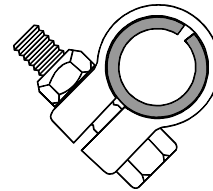
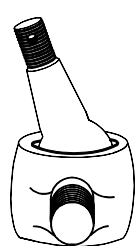
Personal Notes



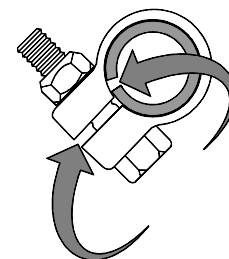
Correct Stud Alignment



Incorrect Stud Alignment



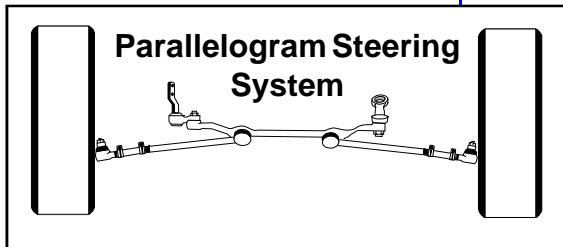
Incorrect Clamp Alignment



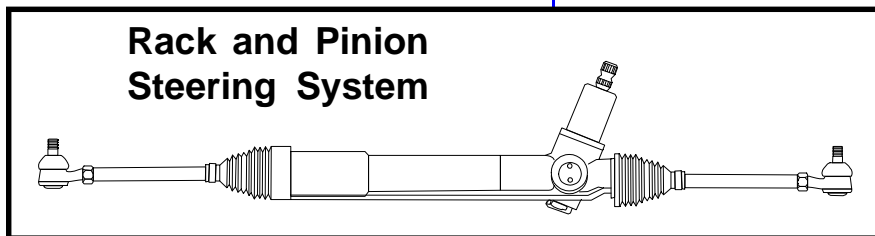
Correct Clamp Alignment

Rack & Pinion Steering

Earlier, we discussed the parallelogram steering linkage. Recently, that has been replaced with rack & pinion steering, which is simply a redesigned parallelogram. Let's take a closer look at it, and compare the two systems.

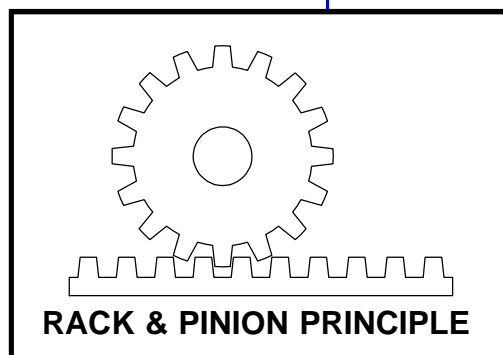


On a parallelogram system the component that ties the right and left sides together is the centerlink. This piece is also in the rack & pinion system, but it has been designed with teeth on one end, and is now called a rack. The centerlink is held in its proper horizontal plane by the idler arm and pitman arm. The rack is held in its proper horizontal plane by the rack housing.



The centerlink is used to attach the tires to the steering system through the tie rod ends. The rack does the same thing, using an outer tie rod end that is very similar to the ones used with parallelogram linkage. The inner tie rod end has been redesigned so that the tie rod stud sticks out very far, and the socket itself screws onto the end of the rack.

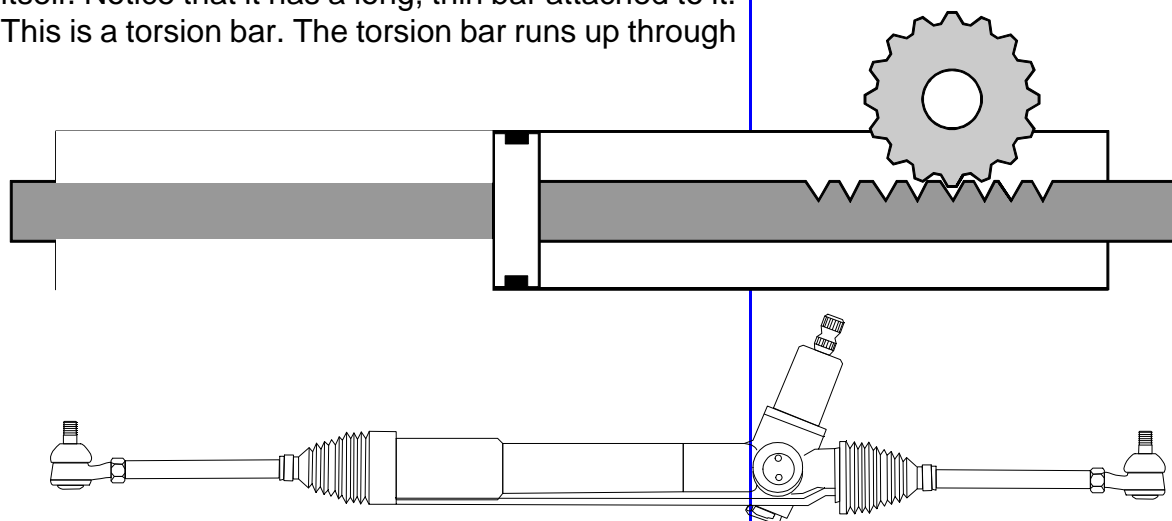
If you look carefully at an installed rack & pinion, you will notice that the inner socket assembly and outer tie rod lie in a plane that is roughly parallel to the lower control arms, just like in a parallelogram linkage system. Because of this, it is important that a rack & pinion be installed correctly. If the mounting bushings and/or straps are deformed or bent, the rack housing will not be held in the proper position, creating a "bump steer" condition, where the car wanders and weaves after hitting an obstruction in the road.



The last piece of the rack & pinion is the pinion gear itself. This takes the place of the conventional steering gearbox. The steering column is attached to the input shaft, through a flexible coupler. If the vehicle has manual steering, the input shaft simply ends in a gear that meshes with the teeth on the rack. A lash adjuster is located directly below the rack where the meshing occurs. Usually of plastic and spring loaded, this adjuster is used to compensate for any wear in the rack and/or pinion teeth. When an adjustment is needed, consult the service manual for the vehicle to find the final torque specification for steering input. The adjuster is tightened (or loosened) until a predetermined amount of steering wheel torque is required to make the rack move.

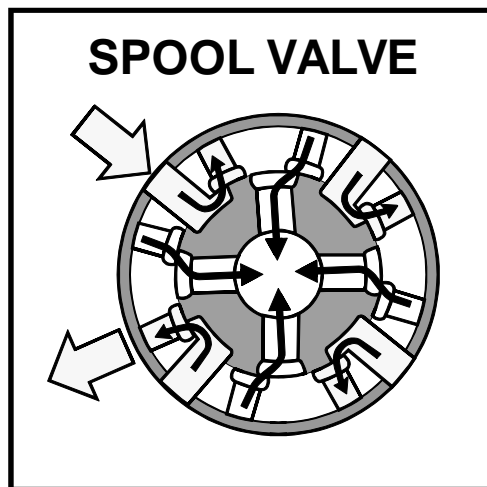
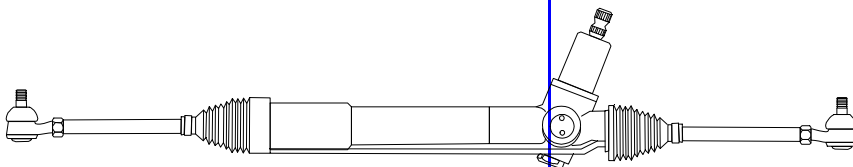
If the vehicle is equipped with power-assist steering, the pinion gear looks slightly different. Instead of a simple one-piece shaft ending in a gear, it is now a three-piece assembly. The steering column is attached, again through a flexible coupler, to the input shaft. This shaft has a machined center section with cutouts in it. These cutouts are called “windows” and the corresponding machined surface is called a “door”. The splined shaft is hollow, with a hole at the top for a retaining pin.

The third section of the assembly is the pinion gear itself. Notice that it has a long, thin bar attached to it. This is a torsion bar. The torsion bar runs up through



the hollow input shaft and is pinned at the top. The splined bottom of the input shaft meshes with a splined section inside the pinion gear. There is a considerable amount of “slop” or free play in this splined section. This is designed so that the customer will have some control over the vehicle when power-assist has failed. As the steering wheel is turned, the free play in the splined coupling is taken up. After the free play is eliminated, the pinion gear meshes with the rack teeth. At this time, the torsion bar begins to twist.

Wrapped around the center section of the input shaft, and attached to the pinion gear, is the spool valve. The inside of the spool valve is a mirror image of the machined “doors” and “windows” of the input shaft. The spool valve is precisely located so that a spool valve door is covering an input shaft window all around the diameter of the input shaft. However, as the torsion bar is twisted, the input shaft moves slightly. As it moves, windows and doors become mis-aligned, and a path for fluid flow is established.

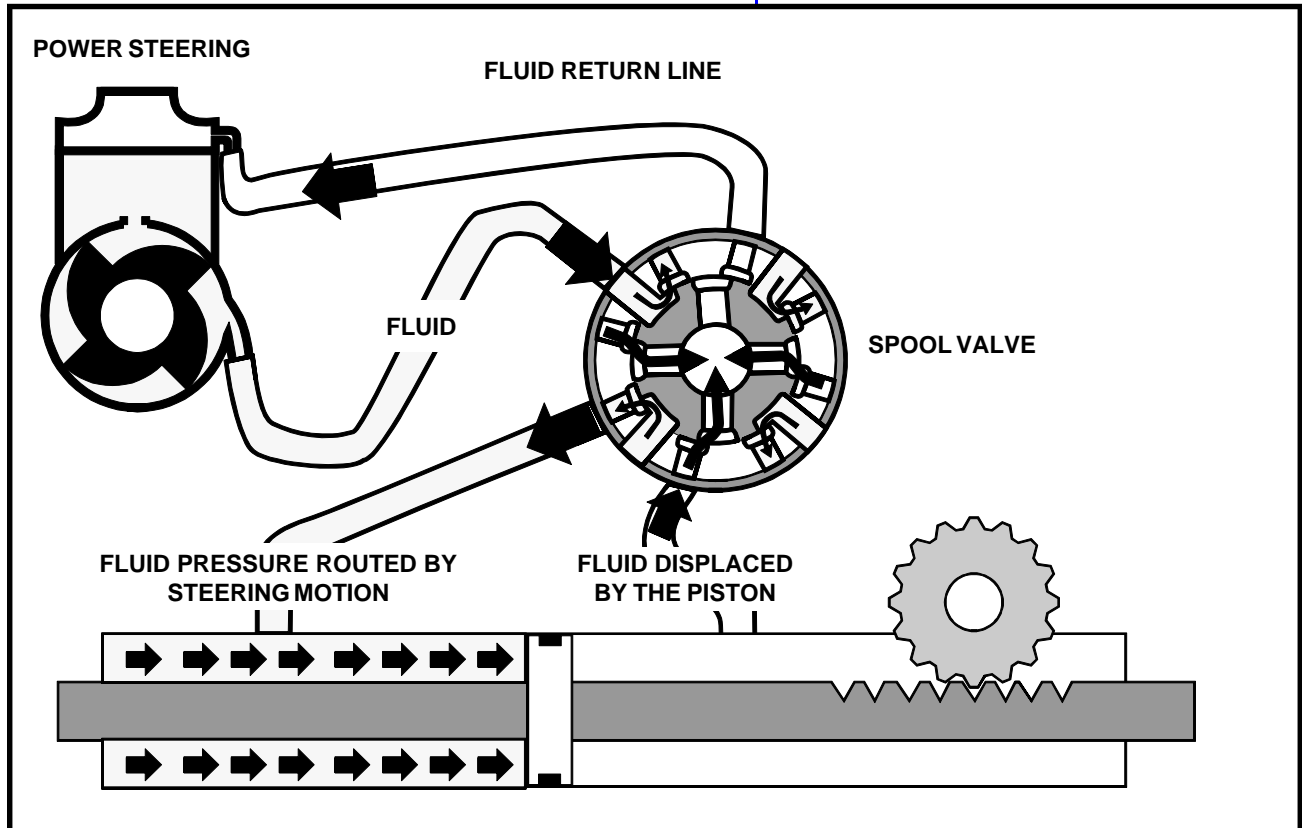


Power steering fluid flows from the pump and enters the rack housing where the spool valve sits. On the outside of the spool valve are several large holes in the center section of the spool. Look inside the spool, and you will notice that the large holes open into the windows. There is also a large hole in the matching input shaft door. With no pressure applied to the steering wheel, the spool valve is aligned with the input shaft, allowing the fluid to simply enter and circulate back to the pump.

On the outside of the spool are two other sections, upper and lower, with smaller holes spaced 45 degrees apart from each other. These holes open into the spool doors. As the torsion bar is twisted by turning the steering wheel, a part of the spool door hole and the input shaft door hole begin to line up with each other. The power steering fluid is forced through the smaller holes, and exit into a tube.

Attached to the rack is a piston with a Teflon seal. The seal presses against the rack housing to divide the housing into two sections. As fluid is directed from the

spool valve, it enters one of two tubes. These tubes are positioned to enter the rack housing on either side of the piston. If the fluid under pressure enters on the left side of the piston, it will push against the piston. Since the piston is attached to the rack, the rack moves to the



right, and since the tie rod ends are attached to the rack, they also are pushed to the right.

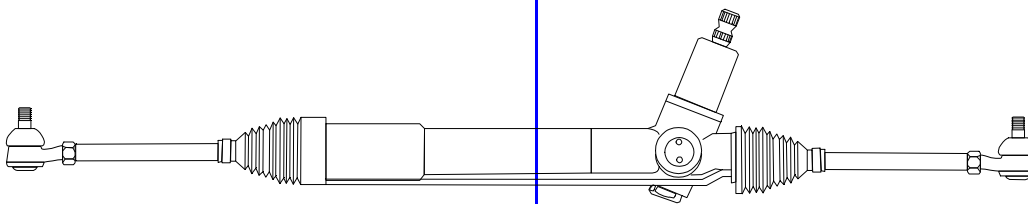
If the rack & pinion is installed behind the front axle (rear steer), as the rack moves to the right, the tires will be steered to the left. If the rack is installed in front of the axle (front steer), the tires would go to the right.

At each end of the rack housing are seals that keep the fluid inside the pressure chamber, as well as keep contaminants from entering and corroding the rack and/or chamber. If these seals go bad, the pressurized fluid can leak past them and enter the protective bellows boot that surrounds the inner socket assembly. By squeezing the bellows, you can feel for any fluid in them. If the problem remains, the bellows will eventually balloon up and rupture.

There is a tube that runs from one bellows to the other. This is the breather tube. It is used to equalize the air pressure within the bellows during turns. Any fluid that enters one of the bellows will be pumped to the other one as the vehicle is turned to the right and left. These bellows can hold up to approximately 1 quart of fluid before rupturing. If you have a customer complaint of having to add fluid to the reservoir, without any signs of leakage present, it would be a good idea to check these bellows.

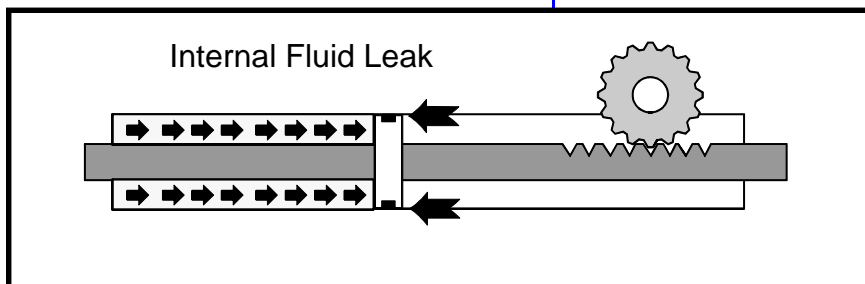
Another common customer complaint has to do with hard steering. Primarily, hard steering complaints can be divided into two areas; those that occur constantly, and those that occur only during the first hour of driving.

If the customer complains of hard steering constantly, check the power steering fluid level, power steering



pump belt and the power steering pump. If no problem is found in these components, a very likely problem area is the pressure chamber inside the rack & pinion. After several thousand miles of driving, the hard Teflon seal that is around the power piston begins to wear a barrel shaped area, on either side of the piston, in the chamber wall.

As fluid enters the chamber from the spool valve, it is supposed to push against the power piston; instead, some of the fluid by-passes around the piston. This results in pressurized fluid on both sides of the piston, creating a hard steering effect. This problem cannot be cured by simply rebuilding



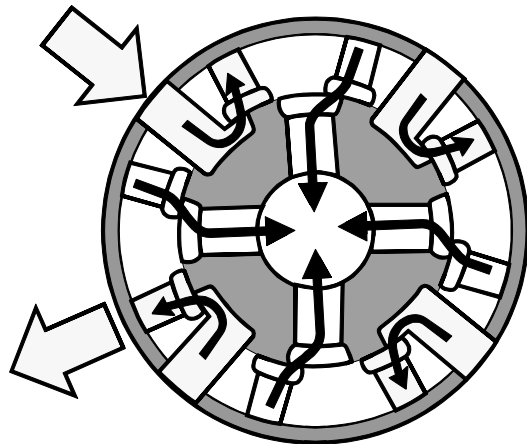
ing the rack & pinion, and calls for complete replacement of the unit.

The other hard steering problem is usually preceded by the customer complaining of a hard steering effort in one direction or the other, usually the first thing after starting the engine. This condition may last for several

minutes to an hour or more and then normal steering is restored. This complaint stems from a leakage around the spool valve seals. In theory, the spool valve seals should be pressed tight against the bore of the housing, while the spool itself rotates. In reality, that is not always the case.

The housing, which is generally made of aluminum, expands and contracts with temperature variations. The spool valve, which is made of steel, and the seals, which are made of a Teflon and Fiberglass composition, also expand and contract, but at different rates. This results in the aluminum housing getting bigger than the diameter of the seals. As the spool valve rotates, the seals also are now free to rotate, and as they do, they slowly erode the smooth aluminum bore into a grooved aluminum bore. As the vehicle sits overnight and cools down, everything shrinks back to its original size. This leaves a gap between the spool valve seals and the groove in the housing. As the car is started, the fluid, which is supposed to enter the pressure chamber when the steering wheel is turned, simply by-passes around inside the spool valve housing, resulting in little or no power assist to the power piston inside the rack housing. However, as the fluid heats up and the ambient temperature heats up, the seals slowly swell and begin to press up against the bore, restoring the power assist. After-market manufacturers are installing steel sleeves in this bore to eliminate the erosion from the seals.

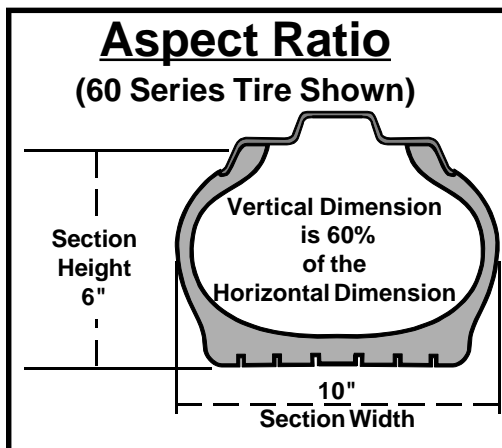
Internal Spool Valve Leaks
can cause hard steering



ALIGNMENT ANGLES

Automobile manufacturers have understood for many years that their products weaken and wear after a period of time. Springs weaken and begin to collapse. Suspension parts and steering parts wear out and become loose. Frames bend or collapse slightly. All of these things combine to make the car less pleasurable to drive. It is also more costly in terms of gas consumption, accelerated parts wear and increased tire wear.

To help decrease these problems, auto manufacturers designed a method of adjustment into the suspension and steering systems. These adjustments allow a technician to compensate for wear related changes. A set of specifications with allowable tolerances has been established by the auto manufacturers. Vehicles are measured and these measurements are compared to the specifications. Those measurements that are not within the allowable tolerances must be adjusted. These settings are referred to as the alignment angles. Just as any measured setting, such as brake rotor thickness, or spark plug gap, a reliable and accurate measuring device must be used. These alignment angles, when measured and adjusted to the recommended settings, should restore the vehicle's handling, ride, and tire life to what they were originally designed to be.



Tire Inspection

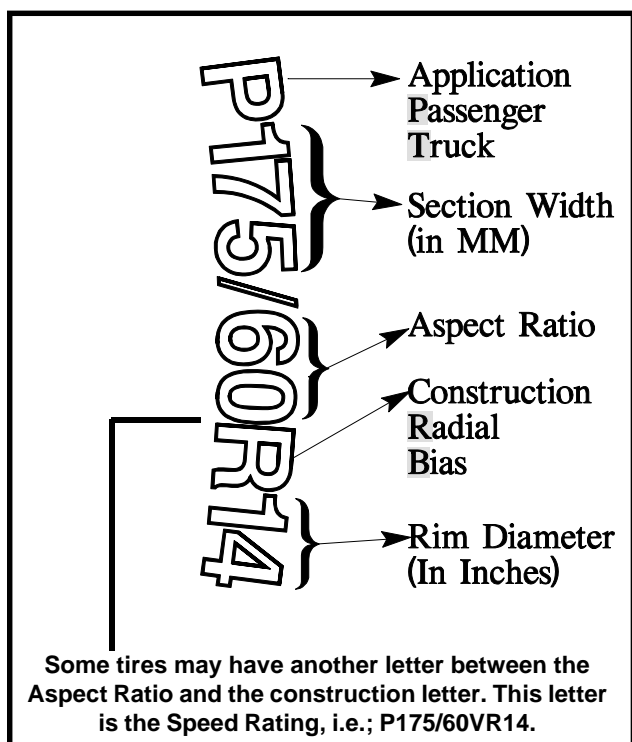
A thorough inspection can aid in diagnosing some four-wheel alignment problems. Tire wear patterns are like a visual graph of camber and toe condition. *Feathered or sawtooth* wear might indicate a severe toe problem on the front. Single shoulder wear would probably lead to a camber or toe problem. Diagonal cross-tread wear on the rear tires is an indication that the rear camber and/or toe needs correction.



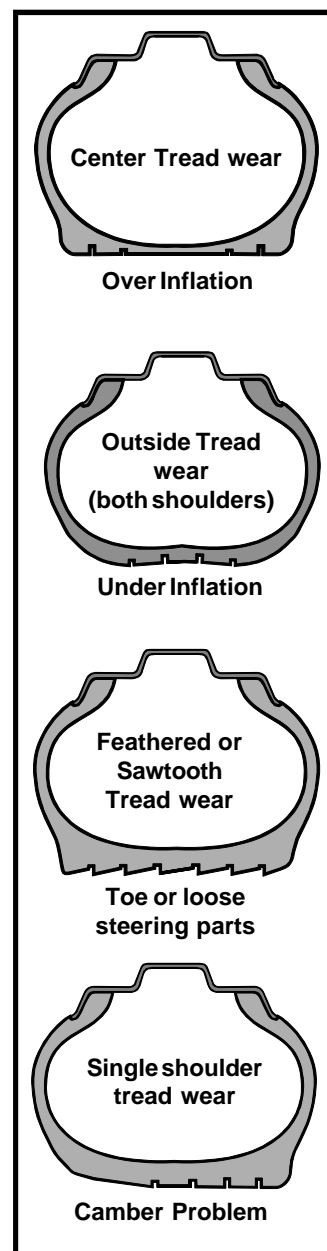
Wear patterns can also help diagnose other problems. Wear on both shoulders might indicate low inflation or loose steering parts. Center tread wear usually leads to an over inflated condition. Cupping could lead to a wheel balance problem and/or bad shock absorbers or other suspension parts.

Check the tires for those not-so-obvious conditions as well. Check the tire sizes. The tires should be the same height all around the vehicle. Tires should be inflated to manufacturer's recommendations. Con-

sult the tire guide or the vehicle decals for the proper inflation pressure. Vehicle decals may be found under the hood, on the door post or on the glove compartment door. These decals may also list the proper tire size. Check the tires for damage. Check all tires for a common tread design. Check for different tire brands. If different, this may cause a directional pull that alignment will not correct. Measure the height of each tire to assure that you do not overlook a tire problem. If the driver complained of a vibration, check the runout of each tire and balance the tire(s) if necessary. All tire related problems should be resolved prior to performing the alignment.



Personal Notes

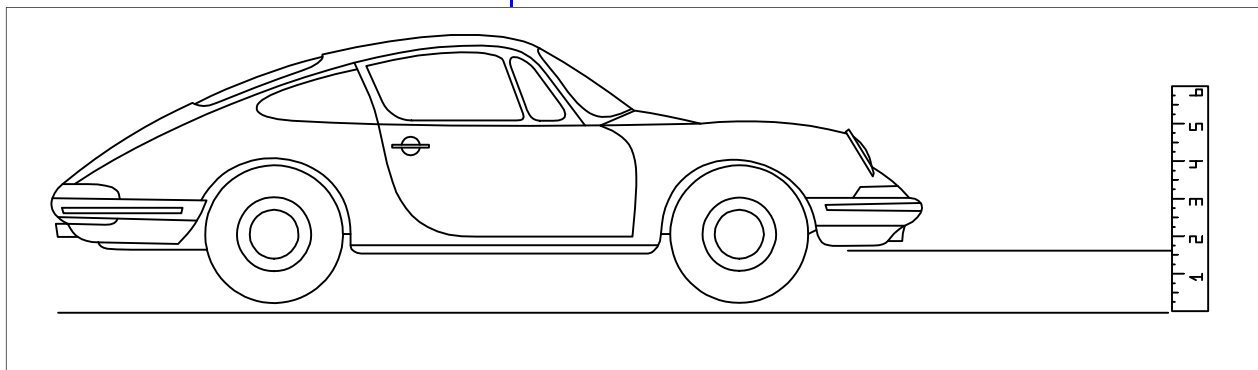


RIDE HEIGHT

The first measurement is the one engineers use to determine all of the other angles. Its name is **RIDE HEIGHT**, **TRIM HEIGHT**, or **CURB HEIGHT**. This setting is used to establish the correct suspension height at which all other angles are measured. An incorrect ride height usually indicates that the springs have weakened and collapsed. If the ride height is incorrect, it can cause handling and tire wear problems. This is because the suspension is operating through different and incorrect geometry. In your alignment specs guide you will find a ride height measurement at the end of each manufacturer's section. If the ride height is not within the allowable manufacturer's tolerances, the amount of adjustment movement will be reduced. In some cases the adjustment may not be possible.

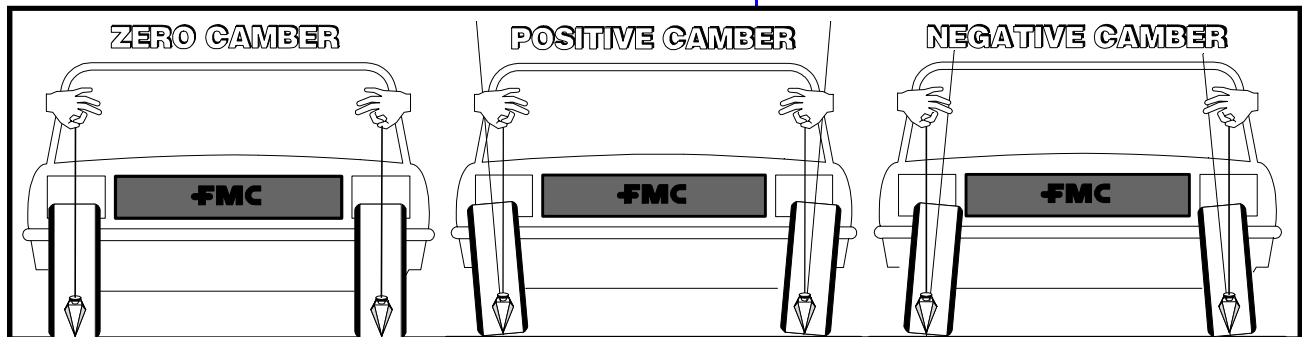
Ride height must be checked and corrected prior to making any other alignment corrections.

If the vehicle is equipped with an electronic ride control system, the system must be operating correctly to achieve proper alignment settings. Some systems may require that the system be disabled prior to alignment. Consult the vehicle service manual for specific details on Electronic Ride Control devices.

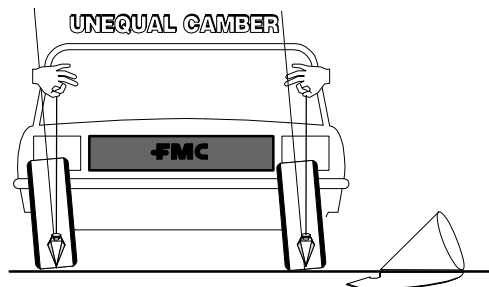
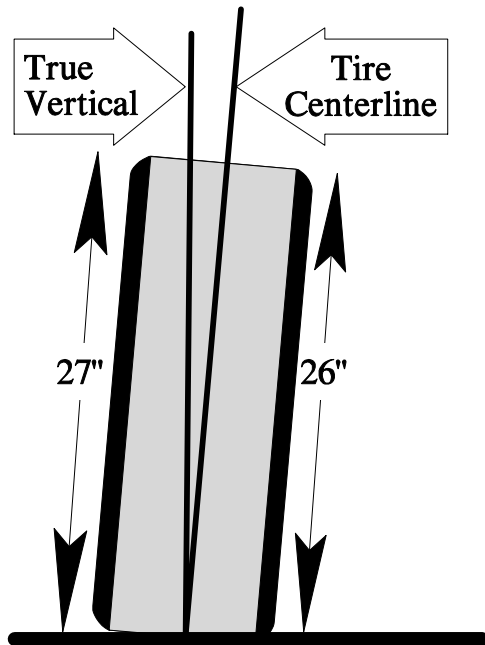


CAMBER

A tire may be in any of three positions: the tire may lean towards the car, it may lean away from the car, or it can be straight up vertically. The camber measurement tells us which of these three positions the tire is in and by how much. If the tire leans **towards the car at the top, the camber is negative**, and the sign (-) is used; leaning **away from the car at the top is positive (+)**; **straight up is zero (0)**. Remember, if you obtain an alignment reading of zero, it does not necessarily mean “no reading”; it is an actual measurement and is often a specification.



The amount of positive or negative camber is measured as an angle from straight up (true vertical). Like an angle, it is measured in degrees. A reading of 1 degree positive would indicate that the tire is leaning away from the car by one degree from straight up. Some specifications for camber are in degrees and fractions of a degree, such as “+3/4”. Others may be in decimal degrees (+.75). Still others may use degrees and minutes, where there are sixty minutes in a degree. A reading of +0,45' is read as zero degrees, forty-five minutes, or three-fourths of a degree.



A proper camber setting is necessary for several reasons:

1. It maximizes the amount of tread in constant contact with the road surface.
2. It helps to establish the proper load point on the suspension.
3. If incorrect, it can cause a pull or lead in the car.
4. It is used, with another angle, to diagnose bent suspension components.

The tires are the only part of the vehicle that touch the road, and the weight of the vehicle reaches the road through the tires. Each tire must support one-fourth of the vehicle weight. If you relate that fact to your own body, your "TIRES" are your feet, and each foot supports one-half of your "VEHICLE" weight. Walking on the outside edges of your feet is comparable to a car with positive camber. What will happen to your shoes after several thousand miles of walking like this? You will wear the outside edges of your shoes. In addition, you will probably notice that your outer ankle is sore and swollen. That is because your weight passed directly through it, instead of being split between the ankles. On a vehicle, the ankles are the wheel bearings, and excessive camber will cause premature wear to the bearings, especially in the case of positive camber and the outer wheel bearing.

If you lean a tire slightly, and then try to roll it, does the tire go straight? What happens? The tire tries to roll away in the direction that the tire is leaning. For this reason, remember that a vehicle will have a tendency to pull or drift to the side with the most positive camber. Camber readings should not vary more than 3/4 degree difference from side to side, unless specified by the manufacturer.

Camber specs are often displayed in this format:

MINIMUM **PREFERRED** **MAXIMUM**

These readings tell the technician that the correct setting (the **PREFERRED** reading) can vary anywhere within the minimum and maximum range, *WITHIN THE SPECIFIED SIDE TO SIDE DIFFERENCE.*

For example:

MINIMUM **PREFERRED** **MAXIMUM**
+1/4° +1° +1 3/4°

These specifications would indicate that the correct setting is a positive one degree. It can vary from positive one-quarter of a degree to positive one and three-quarters of a degree. Therefore we could use the following settings, allowing a maximum of 3/4 degree side to side difference:

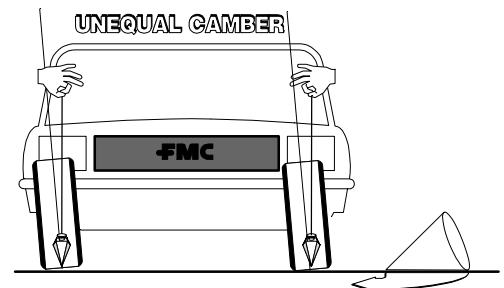
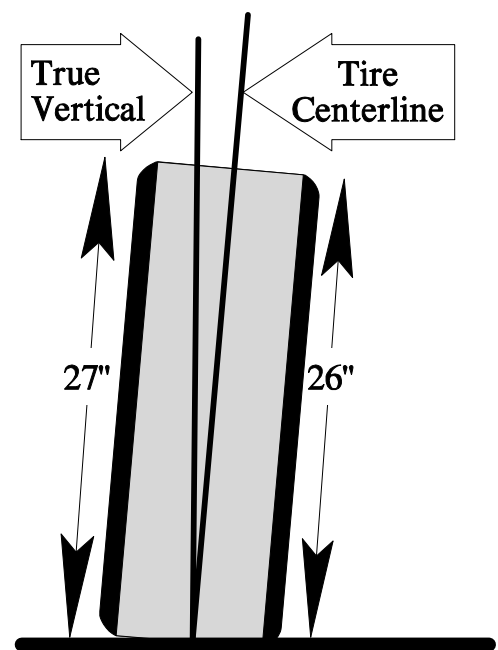
<u>LEFT TIRE</u>	<u>RIGHT TIRE</u>
+1/4°	+1°
+1/2°	+1 1/4°
+3/4°	+1 1/2°
+1°	+1 3/4°

All of these readings are correct, within specifications, and should not cause either tire wear or handling problems. However, if we set the vehicle with the following readings,

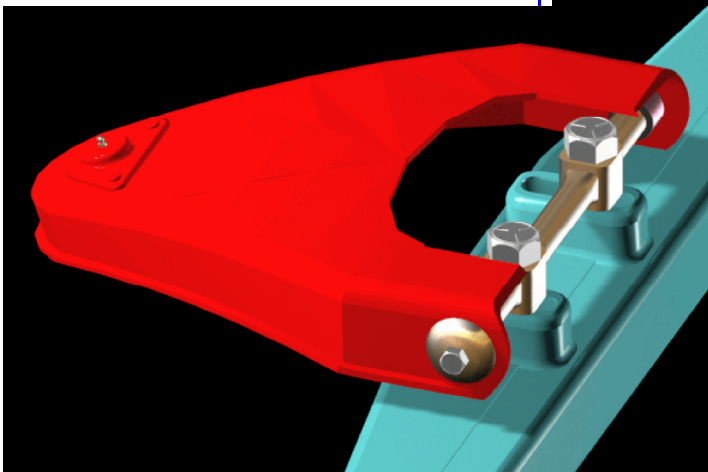
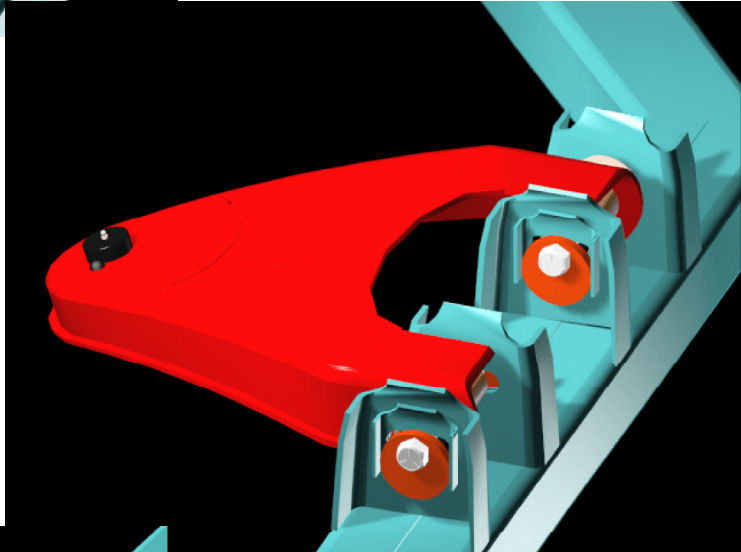
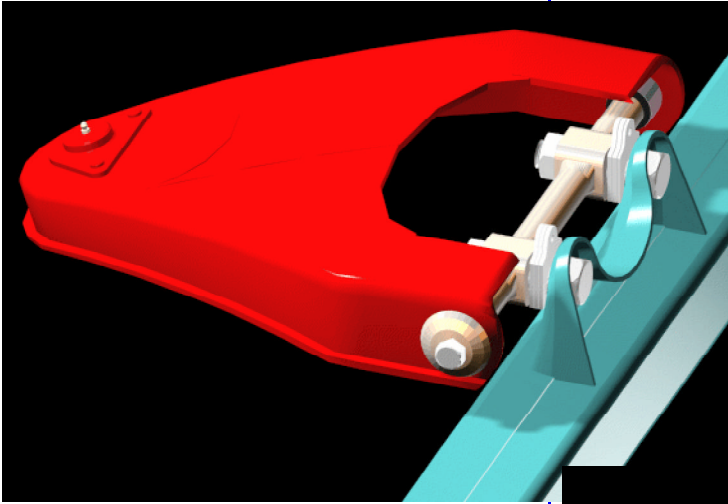
<u>LEFT TIRE</u>	<u>RIGHT TIRE</u>
+1/4°	+1 1/4°

we would still be within specs (between minimum and maximum) but we have exceeded the 3/4 degree side to side difference. This vehicle, while it may not wear tires, would probably have a slight pull to the right, due to the more positive camber on the right wheel.

Personal Notes

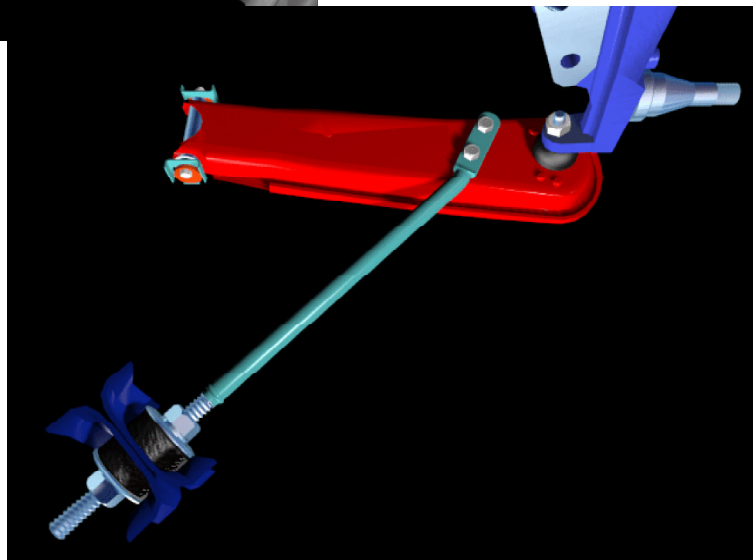
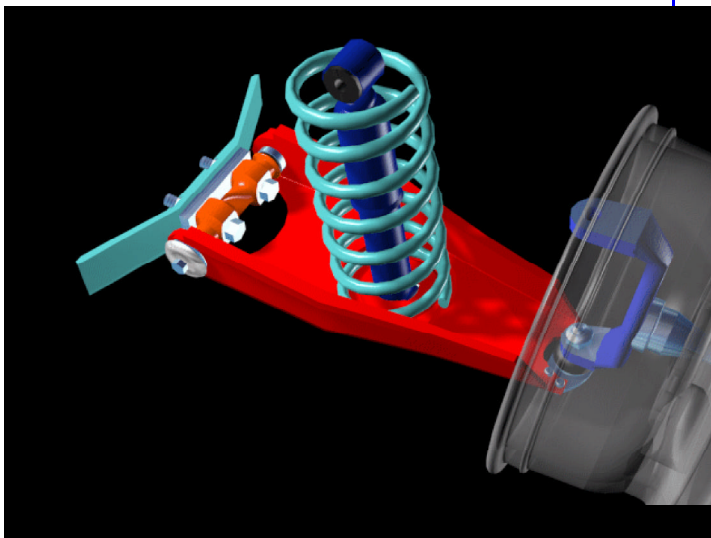
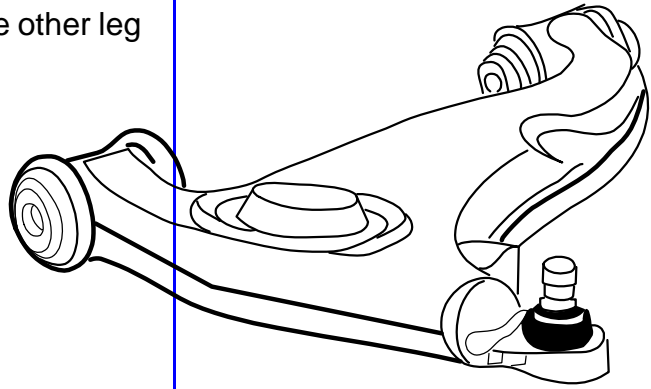


Camber is adjusted in many ways. One of the more common methods is to use spacer shims between the frame and the control arm shaft. As shims are added or removed, the control arm is moved in or out, thus moving the top of the tire in or out. If the shims are inside the frame, adding shims would move the control arm IN, producing a change in camber toward negative. If the shims are located Outside the frame, adding shims would move the control arm OUTWARD, resulting in a positive camber change. When changing only the camber angle, shim movement must be equal at both the front and rear shaft bolts.



Other vehicles may have the shaft mounting bolts attached to the frame through slotted holes. In this case, changing camber is achieved by moving the front and rear of the control arm equal amounts in the slotted holes. Chrysler products often used an eccentric bolt at each leg of the control arm. Camber is adjusted by rotating each cam bolt an equal amount, and in the same direction. Some of the other designs can be found in the rear of your alignment specs guide.

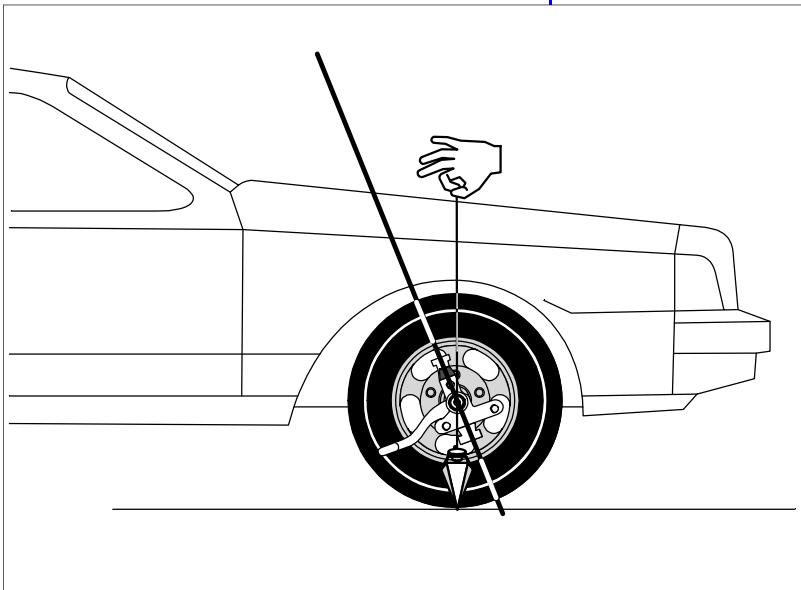
In some cases, the control arm is ***asymmetric*** by design. Notice that one leg of the arm is in a more direct line with the ball joint than the other one. This is the leg that is used to set camber. The other leg is used to set the caster angle.



CASTER

The **function of CASTER** is to *aid proper steering stability*. Caster provides this function by tilting the vehicle's steering pivots (axis) to the front or rear. This axis is an imaginary line drawn through the upper and lower steering pivot points when the vehicle is viewed from the side. These pivot points can be upper and lower ball joints on a SALA suspension system. On conventional strut equipped vehicles, they are the lower ball joint and the upper bearing plate. On vehicles equipped with king pins, the king pin serves as the pivot point.

Positive Caster

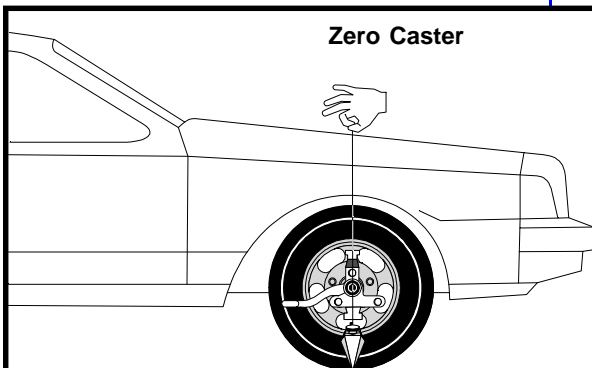


As viewed from the side, this imaginary line drawn through the steering pivots compared to true vertical is **CASTER**. If the top of this line is tilted **toward the rear of the vehicle**, the caster is **POSITIVE**. A **forward tilt** of the line is **NEGATIVE**. If the line is **NOT TILTED**, the caster is **ZERO**.

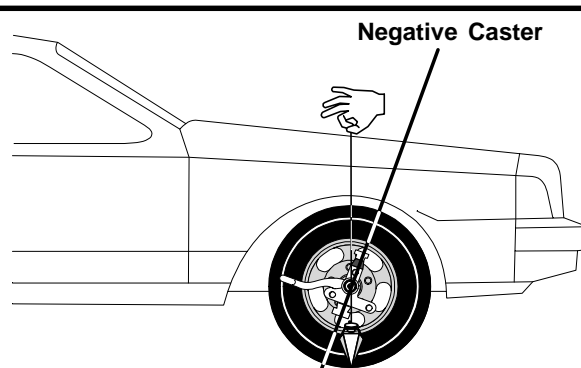
Caster's main function, **DIRECTIONAL STEERING STABILITY**, is achieved through the loading of the spindle. If the caster angle is positive, when the front wheels are turned the spindle on the inside of the turn will move in a slightly downward direction.

At the same time the spindle on the outside of the turn moves slightly upward. Since the tire and wheel are between the spindle and the road sur-

Zero Caster



Negative Caster

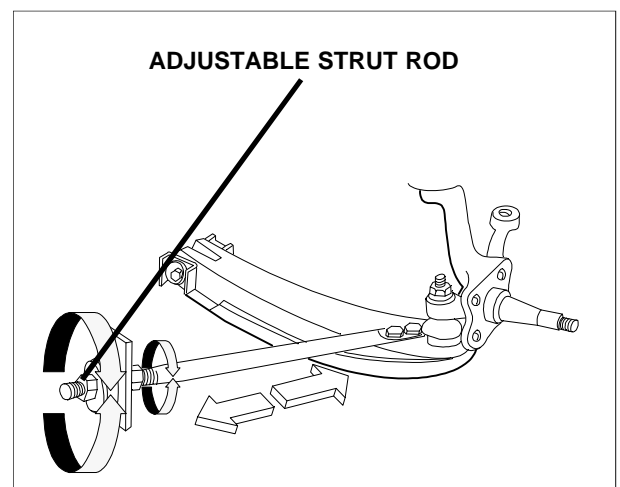
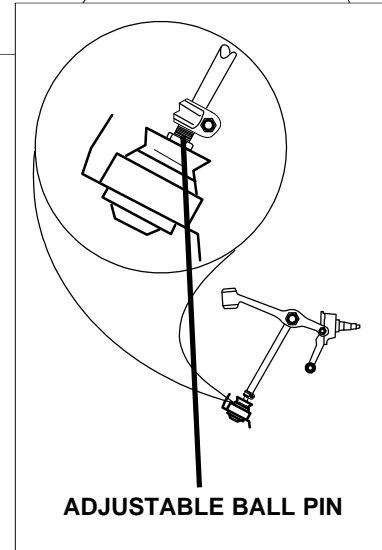
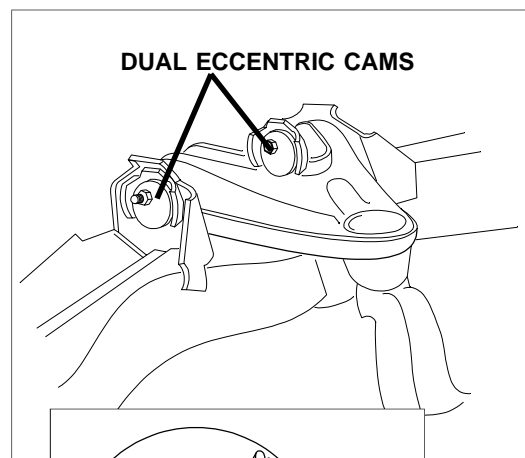


face, the spindle cannot move downward. The result is the spindle that is trying to move downward will lift the chassis upward, therefore increasing the load on that spindle. Since spindles seek equal load, the vehicle automatically tends to steer toward straight ahead if caster angles are equal on both sides. This tendency to return to the lowest chassis position, straight ahead, provides steering wheel return and is considered to be the position of greatest stability. **Increasing caster toward positive will increase directional stability and increase steering effort. Decreasing caster will reduce directional stability and decrease steering effort.**

Caster is generally **not a tire wearing angle**; it is used to *help stabilize the vehicle and make turning away from straight ahead easier or harder*. If a vehicle is equipped with manual steering, the caster angle will usually be quite small, possibly even slightly negative, to make steering easier. However, if the vehicle has power-assisted steering, the caster will normally be set more positive, to give the driver more "FEEL" to the steering. The added positive caster provides more force for the power steering to work against and therefore increasing the stability.

Caster is adjusted several ways. If the vehicle has shims at the upper control arm, adding a shim to the front and removing a shim of equal thickness from the rear will change the caster, without effecting camber.

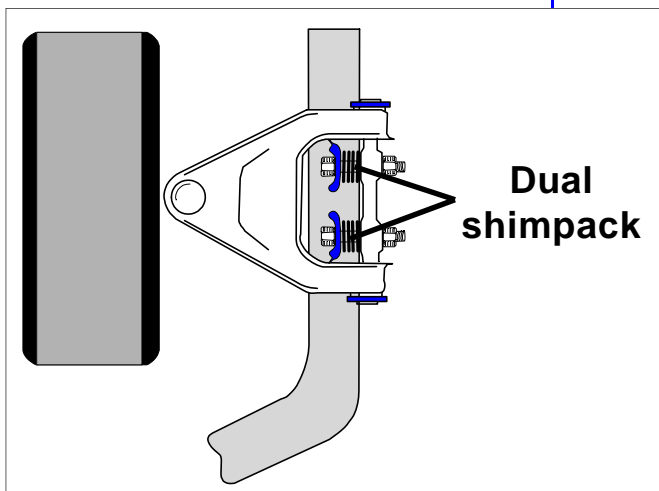
If the control arm is mounted in slotted holes, the front and rear of the arm are moved in opposite directions to adjust caster without changing camber. Likewise, on those arms having **eccentric cam bolts**, turning the two cams equally in opposite directions will change the caster without affecting the camber. Earlier, it was noted that the strut rod was quite often used as a caster adjuster. The strut rod is connected forward or rearward to the frame. If connected forward, lengthening the rod (through adjusting nuts), will move the lower ball joint toward the rear of the car resulting in a decrease in caster. Shortening the rod will change caster in the positive direction.



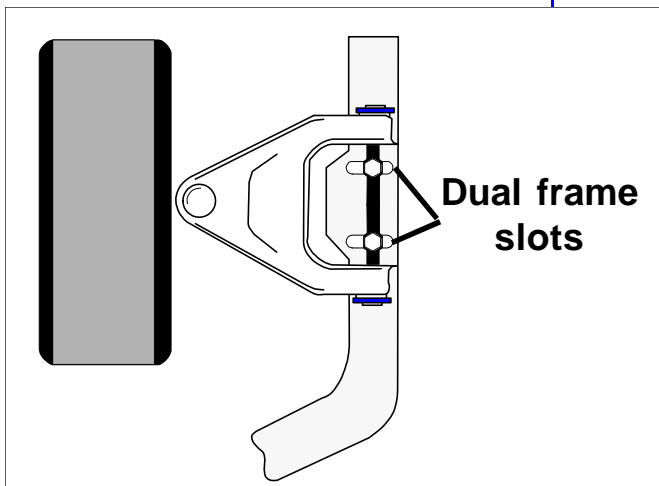
SIMULTANEOUS CASTER and CAMBER CHANGE

So far, you have read about changing one angle or the other, without affecting the other. What about those cases where both camber and caster must be corrected. Is it necessary to adjust first, the caster, and then the camber. Could it be done in only one step instead of two?

There is an old "*Rule of Thumb*" that many alignment technicians have used. It says that placing a 1/8" shim at one end of a control arm will change camber by $1/4^\circ$ and caster by 1° . That means that, adding or subtracting 1/8" shim to both the front and rear bolts of the control arm will change camber by $1/2^\circ$. Likewise, adding 1/8" shim to one bolt while subtracting 1/8" shim to the other, will change caster by 2° . Let's see how this works, when applied to doing both caster and camber.



It is important that you remember that this formula is only a close approximation of what is really going to happen. The formula is dependent upon the size and shape of the control arm. In fact, this formula has an error factor of about 40%. In other words, it will get you close in about 60% of the cars that you adjust.



The shim chart **ON THE NEXT PAGE** shows the approximate total change achieved in caster and/or camber by using the shims listed. To achieve the camber changes listed without effecting caster, **shims of equal thickness must be added or removed**.

The shim size listed for caster results in the total amount of change listed. To achieve

this change the shim size must be split in half and added to one end and the same amount removed from the opposite end. For example, on a vehicle with shims INSIDE the control arm shaft, to change caster 1° toward positive without affecting camber would require a shim change totaling 1/8" be made in the following manner:

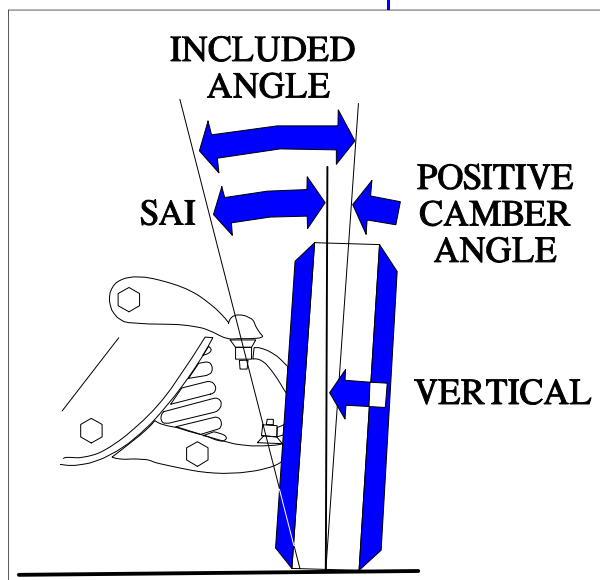
- > Remove 1/16" shim from the front
- > Add 1/16" shim to the rear

STEERING AXIS INCLINATION (SAI)

Earlier you read *"WHEN VIEWED FROM THE SIDE OF THE VEHICLE" a line drawn between the wheel's pivot points (ball joints) was called the caster angle.*

When this line drawn through the steering pivots is viewed from the front of the car, instead of the side, you see that the top of the line leans inward, toward the center. When this line is compared to true vertical, another angle called the **Steering Axis Inclination (SAI)** is formed. In simpler terms, the line is the incline of the steering pivots. When SAI (measured in de-

grees) is measured and used with the camber angle it becomes a very important diagnostic tool. The angle that is formed by including the camber angle is logically called the INCLUDED ANGLE. To include the camber angle, we must ADD the camber angle if positive or SUBTRACT the camber angle if negative. For example, if the SAI is 13.0° and the camber is $+0.5^\circ$ the Included angle is 13.5° . Another example; 12.0° SAI and -1.25° Camber results in 10.75° Included Angle.



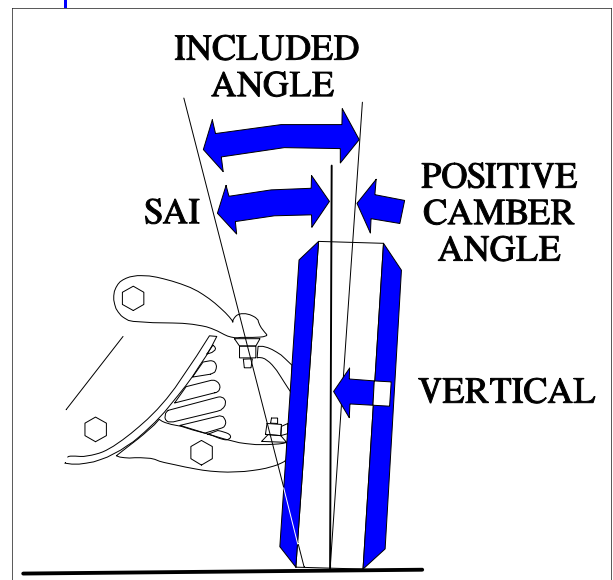
When compared at ground level, the distance between the SAI line (drawn through the steering pivots) and the tire centerline is called **SCRUB RADIUS**. When the scrub radius is toward the inside of the tire tread, the vehicle has **a POSITIVE SCRUB RADIUS**. When the scrub radius is toward the outside of the tire tread, the vehicle has **a NEGATIVE SCRUB RADIUS**.

By altering the SAI angle, which changes the Scrub Radius, the vehicle handling can be designed to better suit driver needs.

Vehicle engineers use these angles to design "Driver FEEL" into the vehicle. They can compensate for downsized compacts, heavy luxury cars, high performance cars or any other desirable characteristic.

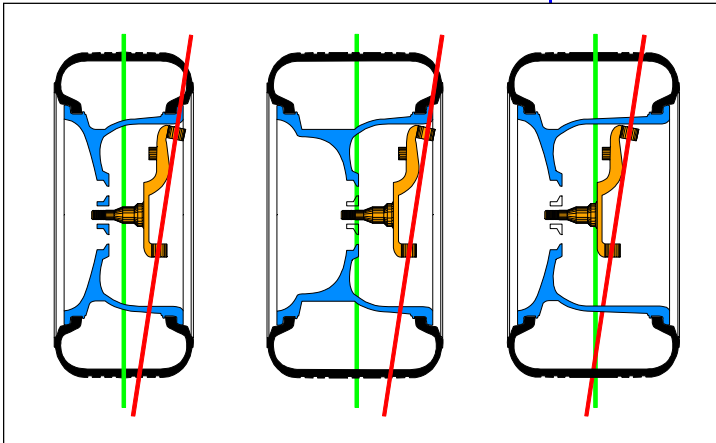
When diagnosing customer complaints related to steering feel, check wheel and tire size. Wider wheels and lower aspect ratio tires can increase scrub radius and therefore alter the perceived steering feel. These changes can alter the handling characteristics of the vehicle, causing wandering or weaving as various road conditions are encountered.

Another function of SAI is to **help provide dynamic stability (when the vehicle is in motion) and steering wheel return**. You may have noticed when you release the steering wheel in a turn, the vehicle tries to return to straight ahead. Also, when turning the steering wheel, one side of the vehicle rises and the other the spindle rotates in a straight horizontal line. If the SAI is tilted the spindle now goes through a horizontal arc. The high point of the arc is when the wheels are straight ahead. When steering the wheels, the spindle tries to drop downward in its arc. Since there is a tire attached to the spindle, and the tire is already touching the ground, the spindle cannot drop. Instead, it pushes up on the knuckle. This causes the lower control arm to push on the spring, which in turn pushes the body up. This, in effect, causes the vehicle's center of gravity to rise also. Gravity does not like to have things UP, so it tries to pull the vehicle back down to its stable position. Where is this stable position? At the center of the arc, which is when the wheels are straight ahead! This arc is compounded by any caster angle. With zero caster, the arc is a simple one, with straight ahead being exactly halfway through the arc. If the caster goes positive, the arc is tilted, so straight ahead is no longer halfway through the arc. As the wheels are turned, one side drops into the arc, but the other side rises in the arc. This is what causes the "tilting" effect to the car body in a turn. The vehicle is designed with a proper amount of SAI, Caster, and Camber. In a turn and as the vehicle side drops, the caster and SAI

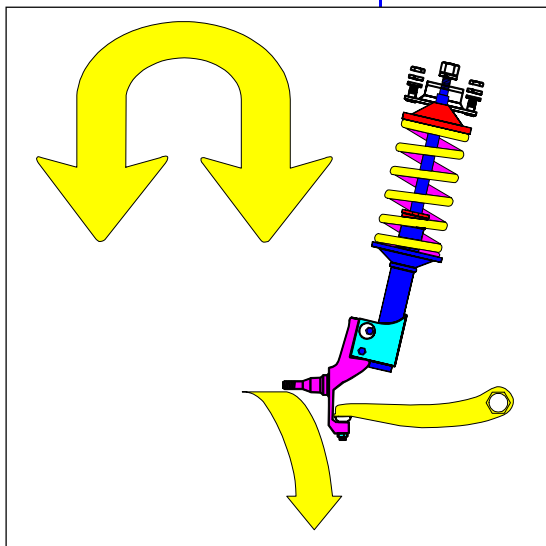


causes the camber to change along with spring compression. This produces a “jacking” effect on the car to help stabilize it during the turn. Caster and SAI will help to pull the tires back to straight ahead when the turn is completed.

Check SAI very carefully if there are problems with pulling or handling that normal alignment doesn't seem to correct. When checking this angle, it is important to assure that the camber is adjusted as close to the preferred setting as possible.

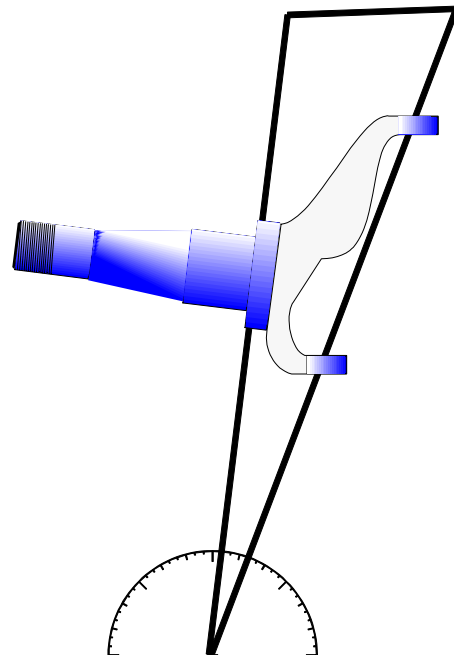
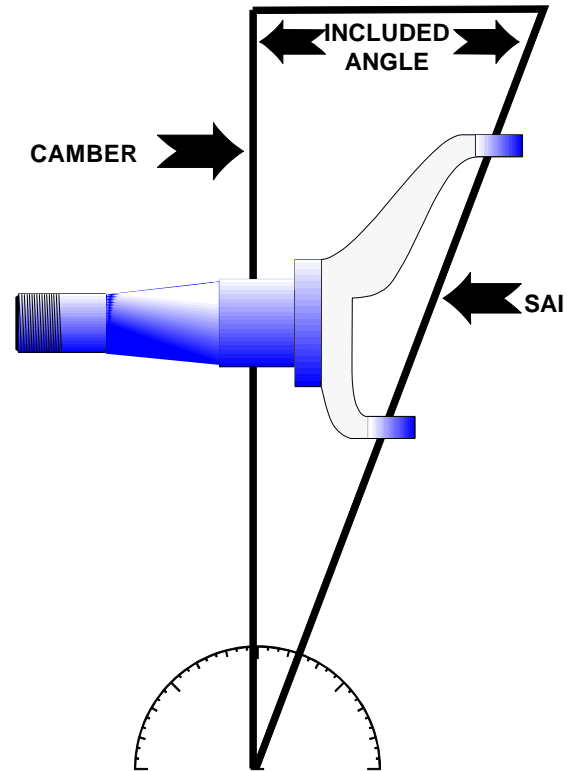
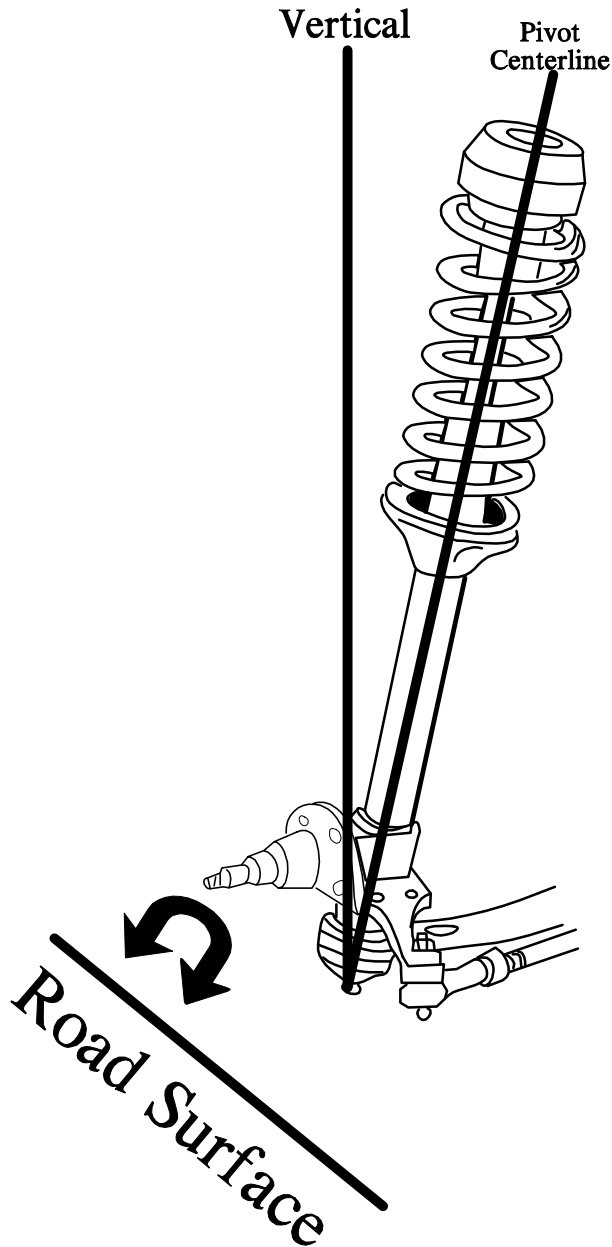


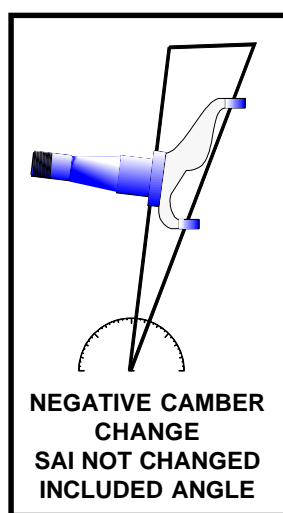
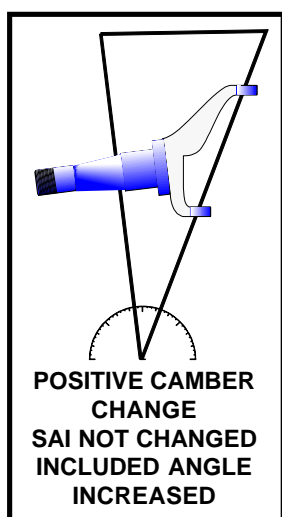
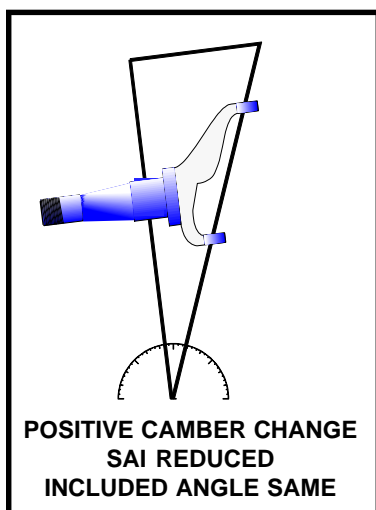
If you look at a steering knuckle on a SALA suspension system, there are *three important connecting points*: the hole where the upper ball joint attaches; the hole where the lower ball joint attaches; and the spindle where the tire attaches. The two holes for the ball joints are responsible for the SAI angle, and the spindle is responsible for the camber angle. If you were to draw a line connecting these three points, you would have a triangle. **This triangle is the Included Angle**, since we included SAI and Camber together. If you turn the steering knuckle, or move it in any way, does the triangle change its shape? As long as the steering knuckle is okay, the included angle will be correct. What if the spindle is damaged or bent? Will that change the shape of the triangle? What if the upper or lower portion of the knuckle is bent? **Any time the Included Angle is incorrect on a SALA suspension the steering knuckle or spindle is bent.**



Is it possible to have incorrect SAI and camber, and still have the correct Included Angle? Suppose a lower control arm was bent in an accident. Would that change the SAI? The SAI would become less, since the lower ball joint moved inwards. As it moved, it brought the knuckle along with it, thus tilting the spindle

downwards. Let's say that the ball joint moved in by 2° . If the original SAI was supposed to be 8° , and the original camber was supposed to be 1° , then the original included angle should have been 9° ($8 + 1 = 9$). By moving outward 2° , the SAI would have been changed to 6° . Since the spindle was moved downwards, the camber would have gone positive by 2° to a total of 3° . Six degrees SAI plus 3° camber equals 9° . So the included angle is CORRECT,





indicating that the steering knuckle is okay, but the SAI is LESS than specs and the camber is GREATER than specs.

Look at the Diagnosis Chart on the next page. Find the row where SAI is LESS, camber is GREATER, and included angle is CORRECT. *What does the chart state as the probable cause?*

By using this diagnostic chart, and accurately measuring the SAI and included angle, you and your alignment machine can solve many of the problems that come into your alignment bays, as well as finding extra parts and labor sales.

Complete a thorough under car inspection prior to using this chart. Replace worn or defective parts and then use the chart to diagnose bent or damaged parts.

SAI Diagnostic Reference Chart

Short Arm/Long Arm Suspension System

<u>SAI</u>	<u>CAMBER</u>	<u>INCLUDED ANGLE</u>	<u>PROBABLE CAUSE</u>
Correct	Less	Less	Bent Knuckle
Less	Greater	Correct	Bent Lower Control Arm
Greater	Less	Correct	Bent Upper Control Arm
Less	Greater	Greater	Bent Knuckle

MacPherson Strut Suspension

<u>SAI</u>	<u>CAMBER</u>	<u>INCLUDED ANGLE</u>	<u>PROBABLE CAUSE</u>
Correct	Less	Less	Bent Knuckle and/or Bent Strut
Correct	Greater	Greater	Bent Knuckle and/or Bent Strut
Less	Greater	Correct	Bent Control Arm or Strut Tower (out at top)
Greater	Less	Correct	Strut Tower (in at top)
Greater	Greater	Greater	Strut Tower (in at top) & spindle &/or Bent Strut
Less	Greater	Greater	Bent Control Arm or Strut Tower (out at top) Plus Bent Knuckle and/or Bent Strut
Less	Less	Less	Strut Tower (out at top) & Knuckle &/or Strut Bent or Bent Control Arm

Twin "I" Beam Suspension

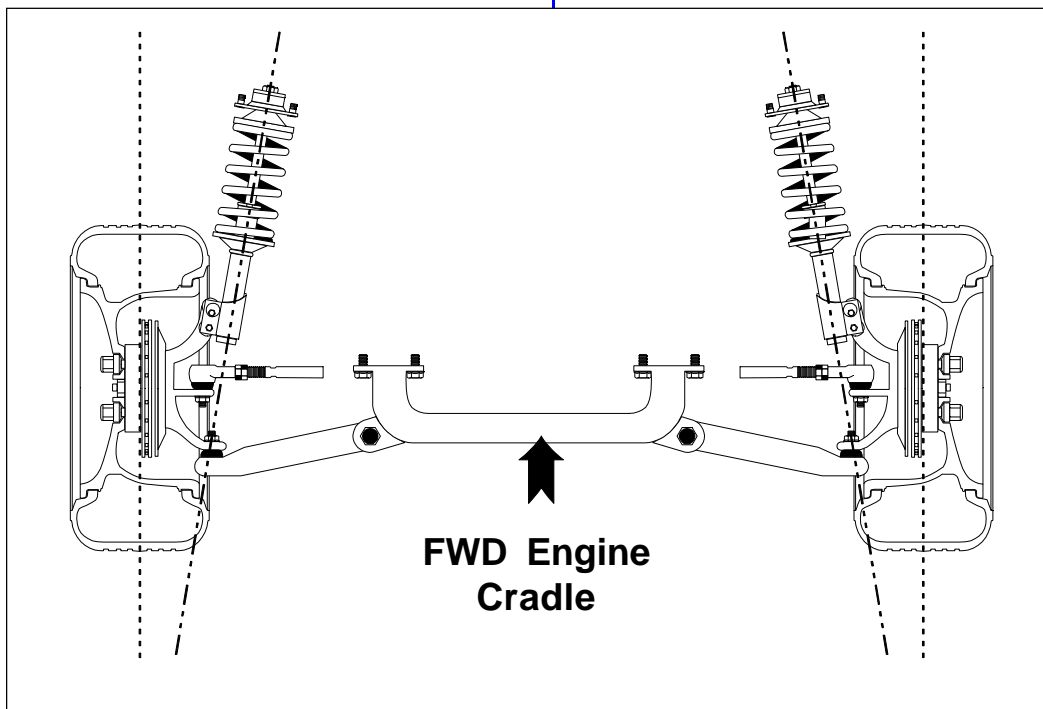
<u>SAI</u>	<u>CAMBER</u>	<u>INCLUDED ANGLE</u>	<u>PROBABLE CAUSE</u>
Correct	Greater	Greater	Bent Knuckle
Greater	Less	Correct	Bent "I" Beam
Less	Greater	Correct	Bent "I" Beam
Less	Greater	Greater	Bent Knuckle

FWD Engine Cradle Misalignment

Many front wheel drive vehicles are designed where the engine cradle also serves as the attachment point for the lower pivots of the suspension system. These modular designs are more cost effective for auto manufacturers because it allows them to completely assemble the drive and front suspension system in one unit. This assembly is bolted to the sub-frame as a unit from the bottom of the vehicle. The assembly must be properly aligned with the sub-frame to assure that front alignment is maintained.

A closer look at the assembly will show that the inner pivots for the lower control arms are bolted to the

cradle assembly. The control arm is attached to the spindle through the lower ball joint. The strut or upper pivot is attached to the upper end of the spindle and is attached to the upper body via the upper strut mount at the upper tower position to complete the suspension steering axis.



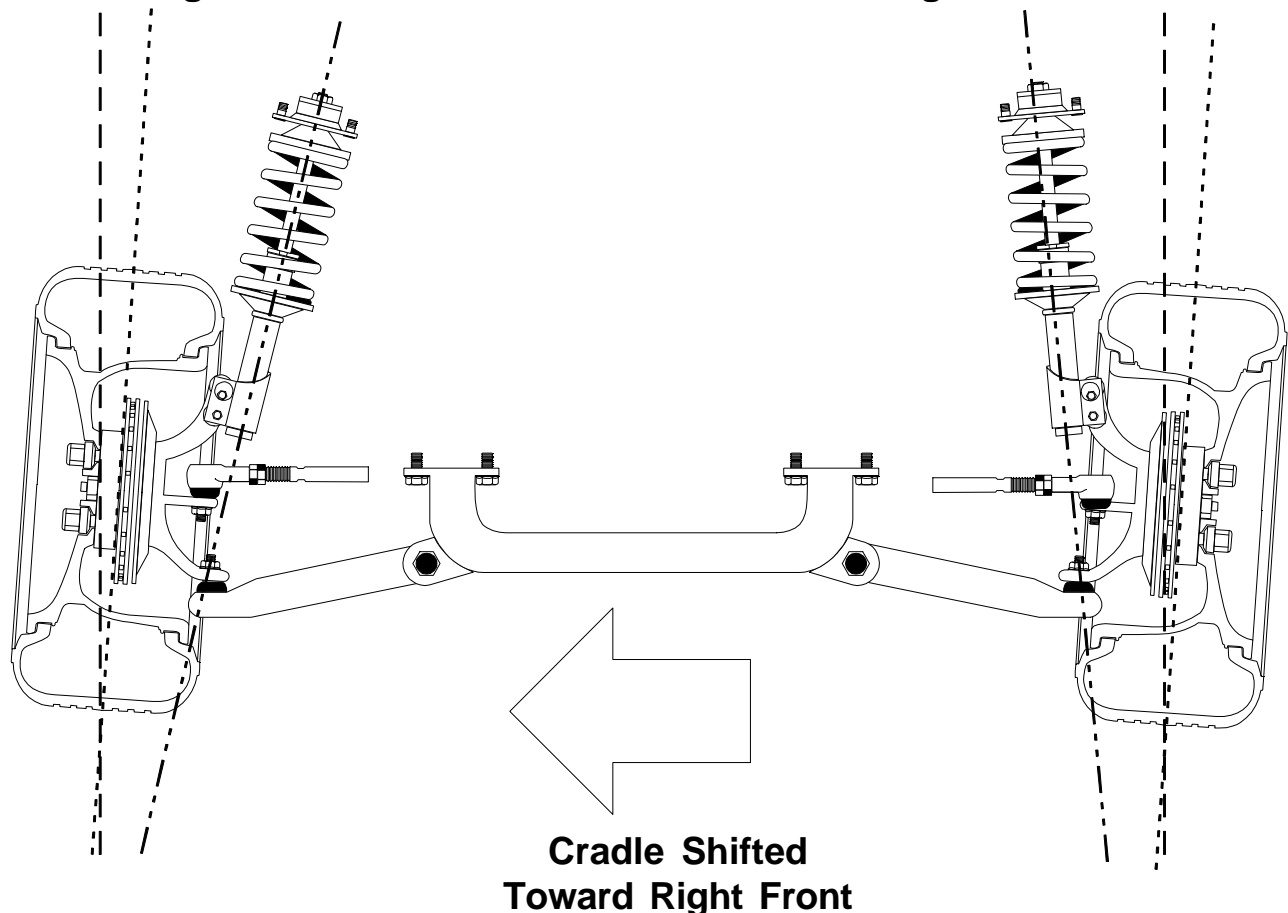
Since the lower control arm pivots are part of the cradle which can move under the sub frame, and the upper pivot is rigidly mounted to the upper strut tower, the alignment of the cradle to sub-frame is critical to wheel alignment. If the cradle is misaligned side-to side, camber and SAI are affected. If the cradle is shifted forward or rearward, caster will be misaligned.

Typically, if the cradle is shifted to the side the SAI will increase and Camber will decrease on the side that the cradle has moved toward and SAI will decrease and the Camber will increase on the opposite side.

The Cradle must be aligned prior to making any other alignment corrections.

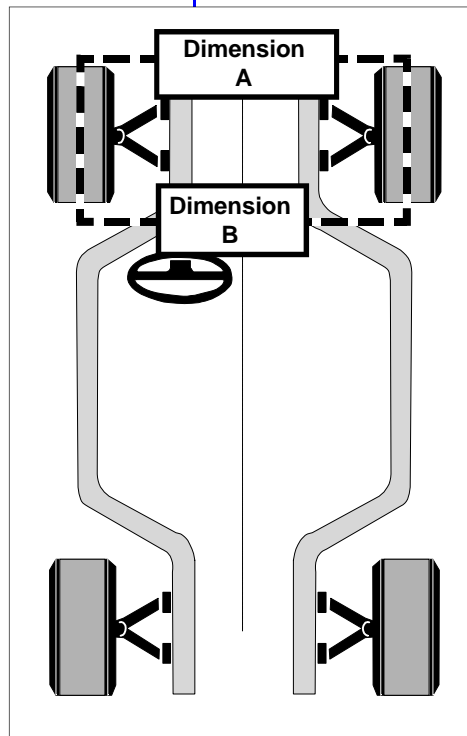
Camber - Decreased
SAI - Increased
Incl'd Ang - Good

Camber - Increased
SAI - Decreased
Incl'd Ang - Good



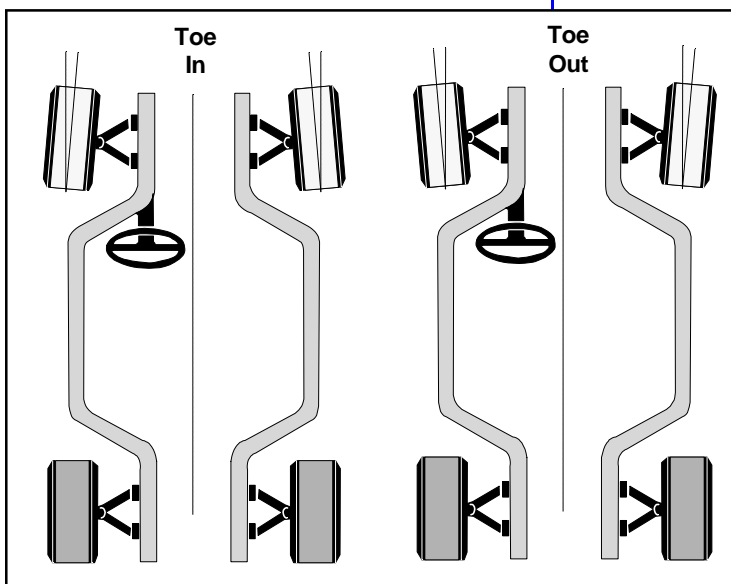
TOE

Earlier it was mentioned that SAI helps to establish the scrub radius. This information with other suspension data enables engineers to establish vehicle toe specifications.



When a vehicle is driven, normal dynamic driving forces try to steer the wheels away from straight ahead. The direction they steer depends on the scrub radius and suspension design. Toe in or toe out, away from straight ahead, is used to compensate for dynamic forces and normal tolerances in steering and suspension parts.

In the illustration to the left, if you measure from the front of one tire to the front of the other tire, you would get dimension "A". If you measure between the rear of these two tires, you would get dimension "B". If "A" is smaller than "B", then we have toe IN. If "B" is smaller than "A", you have toe OUT.



The toe setting is designed to compensate for the amount the tires will turn away from straight ahead. If you adjust toe incorrectly, the tires will not turn enough, or turn too much. In either case, the tires will no longer be going straight down the road. If they are not going straight, they are being "scrubbed" or scraped against the road surface. This will cause the tires to wear out. The rule of thumb is; for only

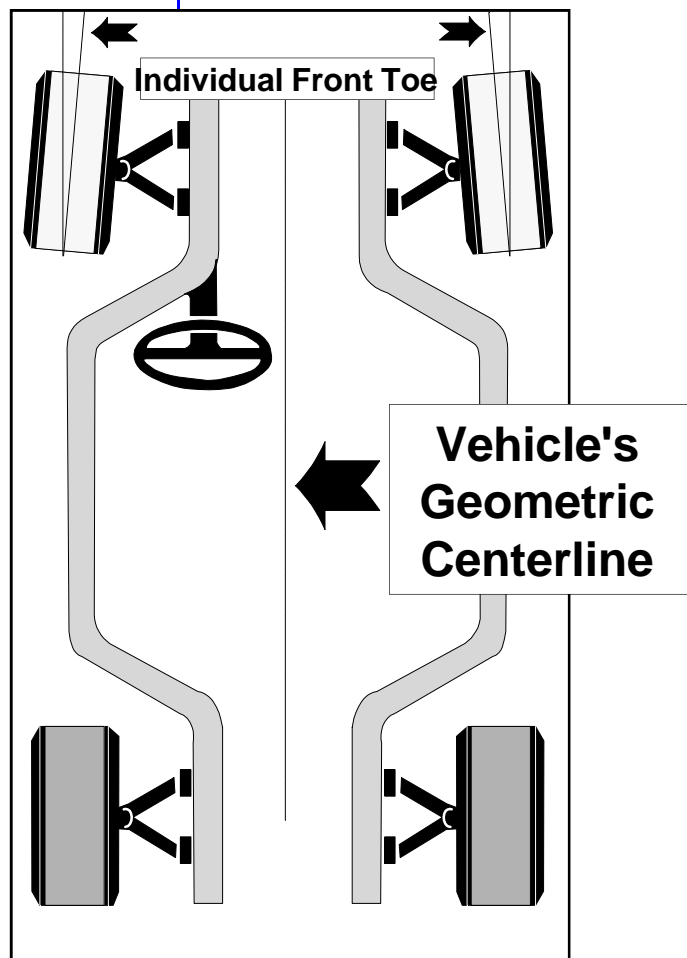
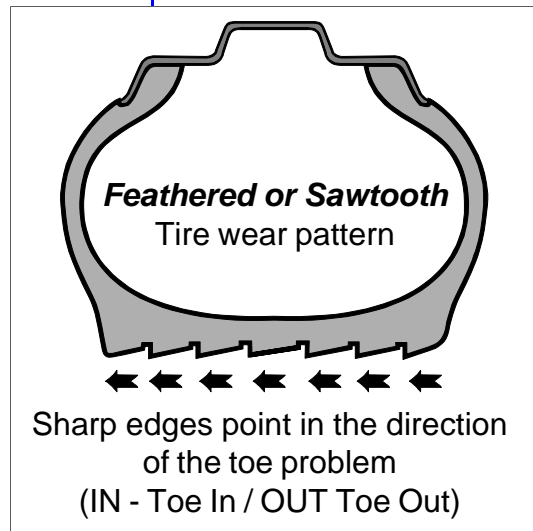
1/8" incorrect toe, the effect is the same as dragging the tire sideways 28 feet for every mile driven. If the tire has toe-in, the outside edge of the tire would be worn faster than the rest of the tire. It would also have a little "feathering" or *Sawtooth* wear pattern at each rib in the tread design. The sharp edges of the wear pattern will point toward the toe problem. In the case of toe in the sharp edges point inward. Just the opposite would occur if the tire had toe-out. This can be more easily seen if you use your feet to represent the tires. *If you walk with the toes pointing to each other, how would your shoes wear?*

Your alignment machine determines where the **GEOMETRIC CENTERLINE** of the vehicle is and then computes the distance from the front and rear of each tire to that centerline.

The reading for each tire is **INDIVIDUAL TOE**. When the individual toe for each tire is added together, we get a reading called **TOTAL TOE**. This is the specification given in your guide. If the total toe (preferred setting) is 1/8", then each tire's individual toe should be 1/16" (1/8" divided by 2).

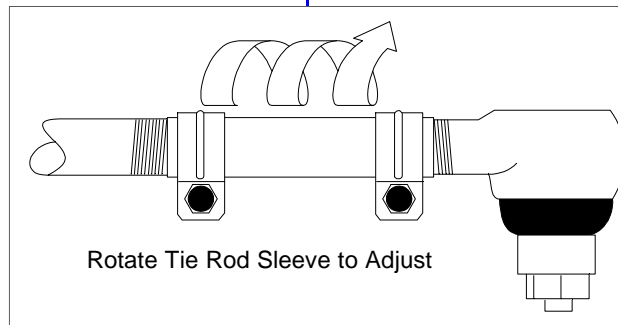
Each tire must be parallel to each other and parallel to the vehicle's centerline when it is rolling down the road. In other words, the **RUNNING TOE** should be near zero.

When adjusting toe, the adjusting sleeves on the tie rod ends are rotated. As the sleeve is rotated, the tie rod assembly is lengthened or shortened. If the steering linkage is behind the spindle centerline (to the rear of the car), lengthening the tie rod assembly will increase toe in.

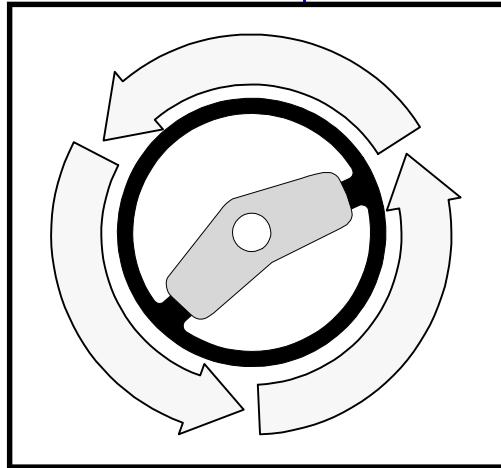


Prior to making individual toe corrections, center the steering wheel and install a steering wheel lock. On vehicles equipped with power assisted steering, it will be necessary to run the engine while centering the steering wheel.

Observe the displayed individual toe readings when correcting toe. Rotating the sleeve on one side can effect the reading on the opposite side if the alignment rack turntables do rotate freely. If the readings on the opposite side change during correction, check the centering of the steering wheel and re-adjust the toe.



When front individual toe is corrected it is either measured in reference to the vehicle's geometric centerline or the thrust angle. Referencing to the vehicle centerline can result in a cocked steering wheel if the rear axle is not squared with the vehicle center. Always referencing to the vehicle thrust line will increase your odds of achieving a straight steering wheel. If the rear toe is adjustable, always make rear toe corrections prior to front corrections unless otherwise specified by the vehicle manufacturer.



The tie rod ends are attached to the steering arm, which is either a part of or bolted to the steering knuckle. Any changes in camber or caster will change the position of the steering arm, and thus change the toe setting.

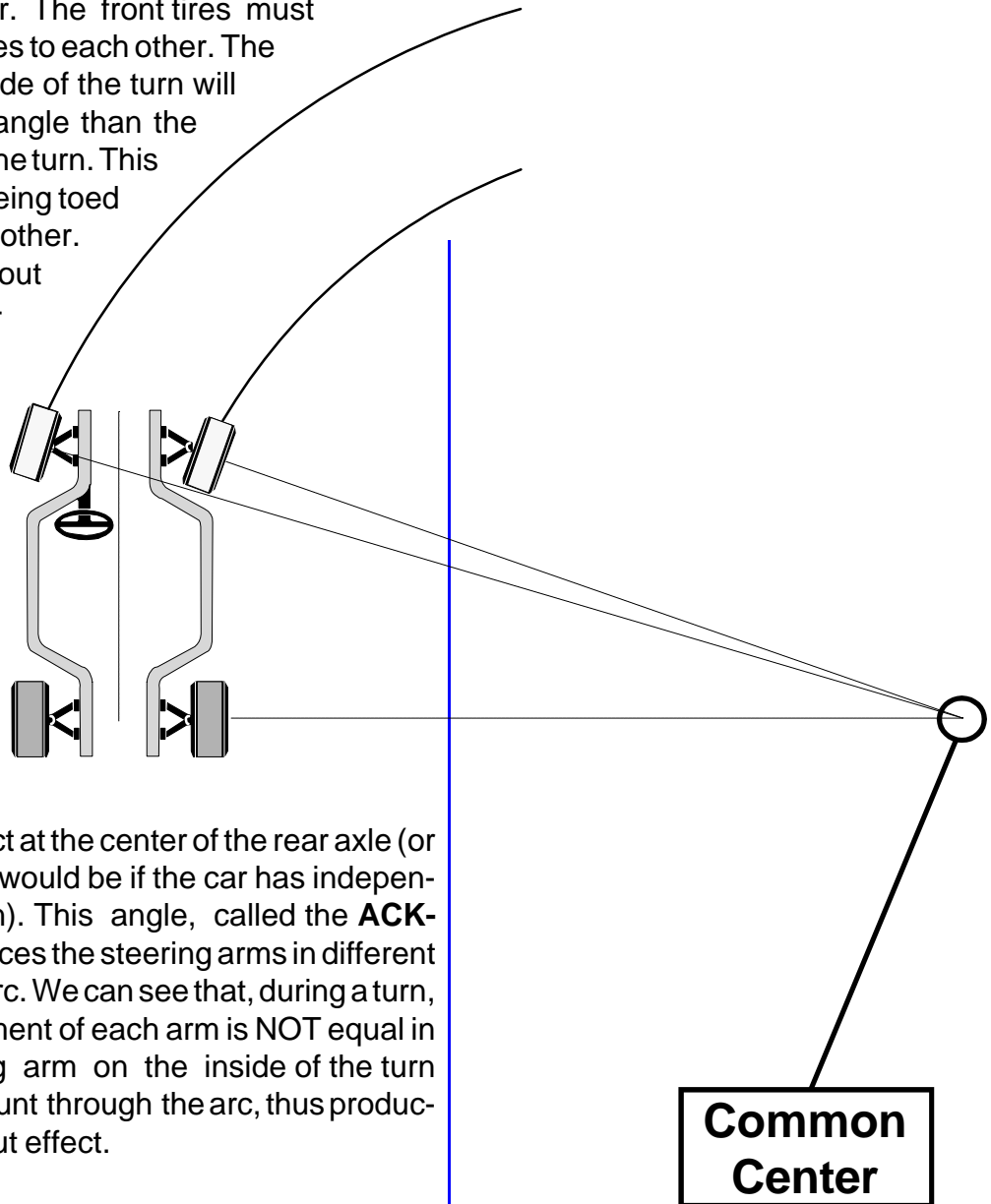
For this reason, the toe adjustment is **ALWAYS completed AFTER the camber and caster adjustments.**

TOE OUT ON TURNS

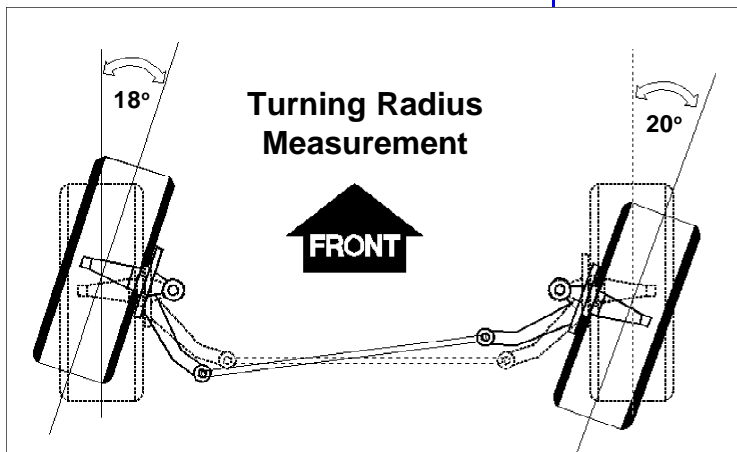
(STEERING GEOMETRY)

As the vehicle goes through a turn, the tires on one side of the vehicle must go through a different size circle than the tires on the other side. The vehicle turns about a common center. This can be illustrated with lines drawn from the center of each front tire that meet with a line drawn between the two rear tires. This is the common center. The front tires must turn on different angles to each other. The tire that is on the inside of the turn will be steered a greater angle than the tire on the outside of the turn. This results in the tires being toed out in relation to each other. The amount of toe out effect will be determined by the angle of the steering arms.

If we look at the steering arms, you can see that they are both angled inward. If we were to draw a line down the center of each steering arm and then extend those two lines, we would see that they intersect at the center of the rear axle (or where the rear axle would be if the car has independent rear suspension). This angle, called the **ACKERMANN ANGLE**, places the steering arms in different portions of a similar arc. We can see that, during a turn, the amount of movement of each arm is NOT equal in the arc. The steering arm on the inside of the turn travels a greater amount through the arc, thus producing the desired toe out effect.



Your alignment specs guide has a column for toe out on turns which is the turning angle. You will see that it calls for two different readings; one for the inside wheel and one for the outside wheel. When measuring toe out on turns, start with the left tire and steer to the left to the specified angle. Use the turning gauge on your turntables to measure the turn angle. After you reach that amount of degrees, have someone tell you what the reading on the opposite wheel is. It should be within $1\frac{1}{2}^{\circ}$ of the specification.

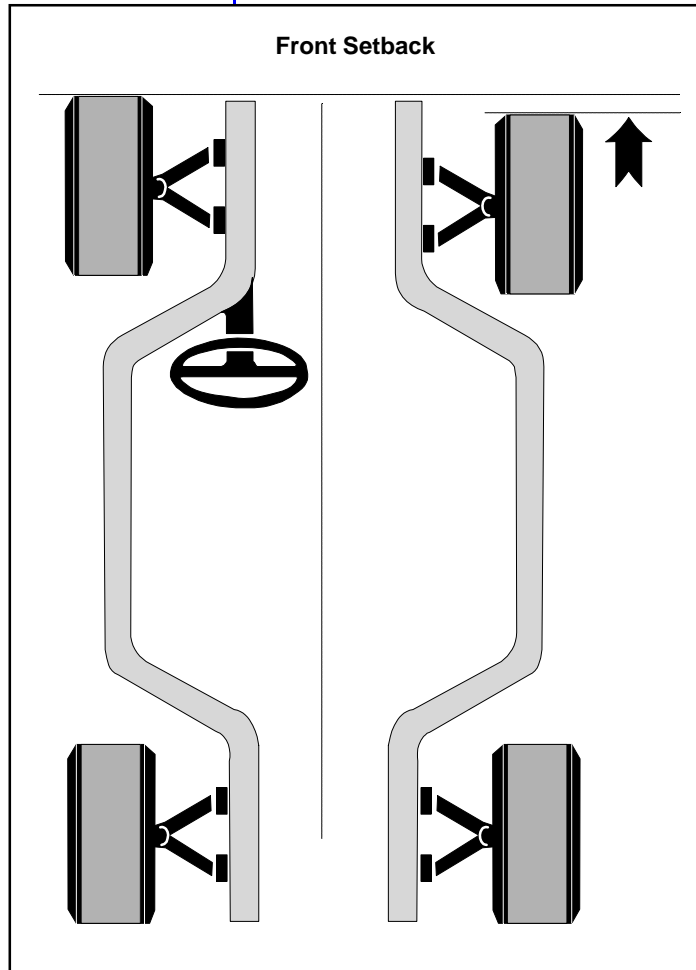


To correct turning radius, the bent steering arm must be replaced.

This angle, like SAI and included angle, is primarily a diagnostic angle. Check this angle when the customer complains of a tire squeal in a turn, or when tire feathering is evident and the toe setting is correct.

Some imports, notably those from Asia, have a slightly different method of checking toe out on turns. If you look in your alignment specification guide for a 1986-88 Hyundai Excel, you will see that the turning angle specification for the inside wheel is $35\frac{13}{16}^{\circ}$. The specification for the outside wheel is $29\frac{1}{4}^{\circ}$. This vehicle has adjustable full-lock steering. Here, the procedure is to turn the steering wheel as far as it can in one direction. When it can be turned no more, read the amount that the inside wheel is turned. If it is not as specified, then go under the car and adjust the steering stop until it is achieved. Not until the inside wheel is at the correct amount of turn can the other wheel be read. Replace the steering arm if the outside wheel is not within $1\frac{1}{2}^{\circ}$ of specification.

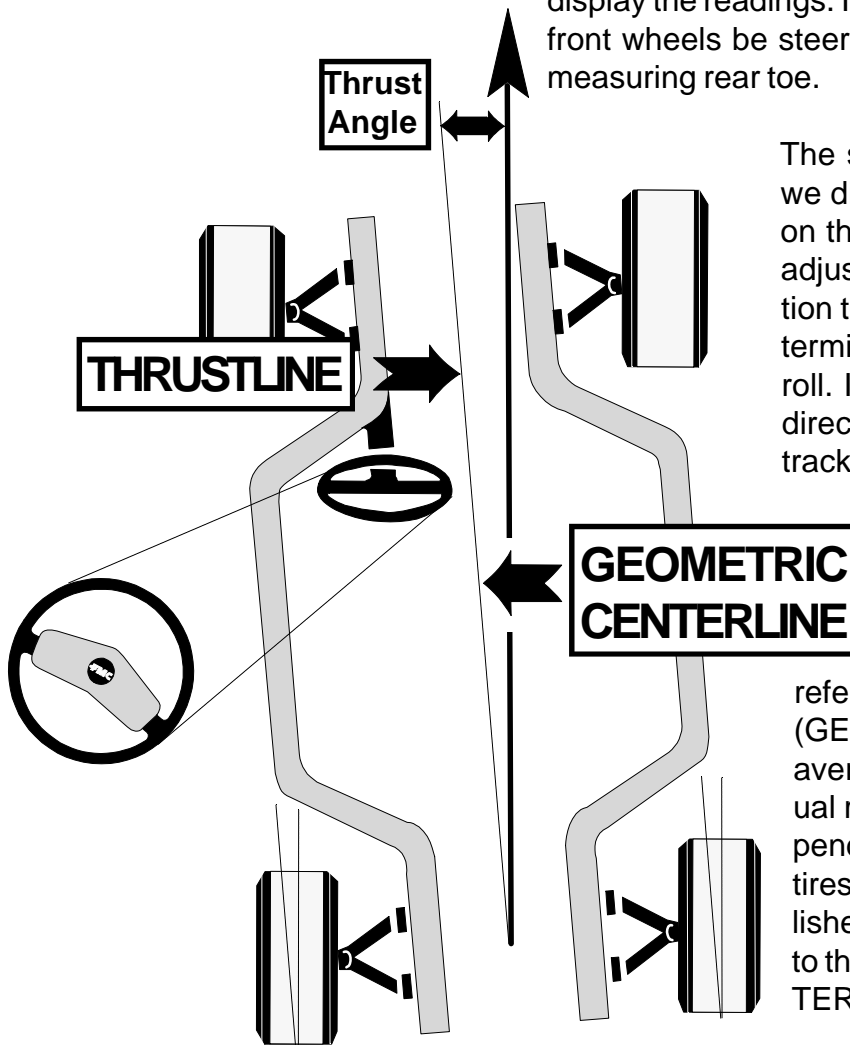
Before measuring toe out on turns, it is important to have both turning gauges set to zero before you begin, and the toe-in setting should be correct. Also, make sure that your turntable gauges read more than 35° . Many older turntables only went to 35° , and need to be updated.



Thrust Angle

We previously discussed front individual toe. Check the rear wheels of all vehicles to see if the rear wheels are parallel to the vehicle's centerline when driving the vehicle. As with front wheels the rear wheel specification allows for the amount of anticipated change when the vehicle is in motion.

Measuring rear individual toe is the same as measuring the front. The alignment system will calculate and display the readings. It is extremely important that the front wheels be steered to equal toe values prior to measuring rear toe.



The same tire wear conditions that we discussed for front toe can exist on the rear wheels if rear toe is not adjusted to specifications. In addition to tire wear, the rear wheels determine the direction the vehicle will roll. If not adjusted properly the roll direction can cause the vehicle to track in a direction that is not parallel to the vehicle's centerline.

The vehicle's roll direction is the vehicle's **THRUST LINE**. When measuring the rear individual toe, it is measured in reference to the vehicle's centerline (**GEOMETRIC CENTERLINE**). By averaging the values of the individual rear toe and drawing a line perpendicular to the center of the rear tires the **THRUST LINE** is established. The Thrust Line compared to the vehicle's **GEOMETRIC CENTERLINE** is the **THRUST ANGLE**.

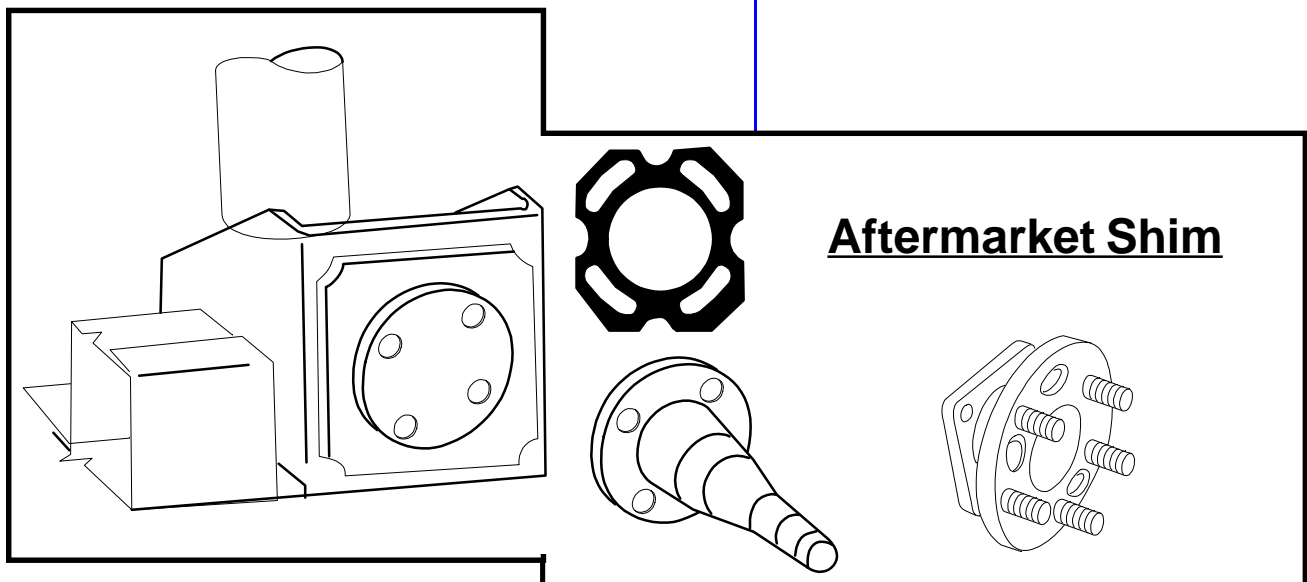
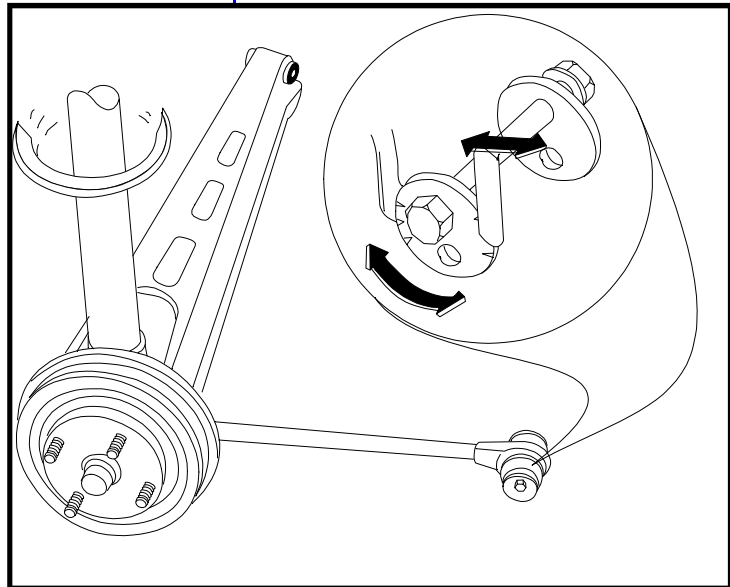
The Thrust Line is the actual direction that the vehicle will travel when driven straight down the road. If the Thrust Line is not identical to the Geometric Centerline, the driver must steer to cause the vehicle to drive in a straight line. This results in a cocked steering wheel in the direction of the Thrust

Line. This misalignment of the rear wheels in relationship to the vehicle centerline also causes the vehicle tracking to be offset (the rear wheels run in a different track than the front). This condition is commonly referred to as “dog-tracking”.

The Thrust Angle should always be near zero. Consult the specification guide for manufacturer's recommendations. The Thrust Angle is adjusted as the rear individual toe is adjusted.

Many vehicles have either built in adjustments or an aftermarket adjustment part is available. On vehicles with a fixed rear axle or non adjustable independent rear suspension, look for worn or damaged parts including the axle itself. Worn rear spring mounts can cause the rear axle to shift. Rear control arm bushings can become worn and allow the rear axle to shift.

If no worn or damaged parts can be detected, use the rear thrust angle as the reference when adjusting the front individual toe. This will compensate for any out of thrust condition and the steering wheel will be straight when driving the car straight down the road.



GLOSSARY

ACKERMAN Principle: An alignment principle based on vehicle tread width and wheelbase upon which turning angle is computed.

Active Suspension: A suspension system in which hydraulic actuators add force to the suspension system to allow compression (Jounce) and extension (Rebound).

Alignment: The process of measuring and positioning all wheels attached to a common chassis.

Angle: Two intersecting lines that are not parallel.

Arc: Any part of a circle or a curved line.

Axial Play: Vertical movement of the wheel and tire assembly when inspecting a ball-joint.

Balance: This term is used to describe having equal weight distribution about the circumference of a wheel and tire assembly.

Ball-Joint: A chassis to knuckle connector consisting of a ball and a socket. This configuration allows for simultaneous angular and rotating motion.

Bead: Steel wire forming an anchor for individual plies and rim attachment of a tire.

Bellows: a Rubber type seal which is folded to allow for a telescopic action. Normally referred to as a bellows boot.

Bias Belted: A tire construction type with overlapping plies at 90 degrees with additional belts formed around the circumference of the tire.

Bias Ply: The same type of construction is used on this design as a bias belted, but without the reinforcement belt.

Body Roll: The leaning of the vehicle body while cornering.

Braking Control: Vehicle stability related to the reaction under all stopping conditions.

Bump Steer; A directional change in steering caused by road irregularities. As the suspension moves through jounce and rebound, changes in alignment at the front or rear wheels may alter the vehicle's directed path.

Bushing: A component made of metal or rubber-type material, used to isolate interconnected moving parts.

Cam Bolt: A bolt and eccentric assembly which when rotated will force components to change a position.

Camber: The inward or outward tilt of the wheel at the top and as viewed from the front.

Camber Roll: A change in camber brought about by suspension changes while cornering.

Caster: The forward or rearward tilt of the steering axis at the top and as viewed from the side.

Center Bolt: A bolt that provides centering and attachment of an axle and spring assembly.

Centerline Steering: A centered steering wheel while the vehicle is traveling in a straight ahead course.

Chassis: All major assemblies on a vehicle including suspension, steering, drive-train and frame; everything except the body.

Circumference: The total distance around a circle.

Coil Spring: Spring steel wire formed in the shape of a coil.

Compliance: The ability of an object to yield elastically when a force is applied.

Concentric: Two or more components sharing a common center.

Conicity: The cone shape that a tire takes through its normal life when inflated and loaded.

Contact Area: The total amount of tread surface that contacts the road.

Control Arm: An arm that is used to attach a spindle or axle to the chassis.

Cornering: The ease at which the vehicle travels a curved path.

Cradle: The framework of a front wheel drive vehicle that provides the engine mounts as well as front suspension pivot points for many vehicles.

Curb Weight: The overall weight of a vehicle less passengers, luggage, or load.

Degree: A unit of measurement to describe an angle.

Dial Indicator: An instrument used to measure and display linear displacement. Measurement is displayed on a dial face and the scale is commonly graduated in thousandths.

Directional Stability: The tendency for a vehicle to maintain a directed path.

Drag Link: A tube or rod used for interconnection between a pitman arm and tie-rod assemblies.

Dry Park Check: Inspection of chassis & steering parts with the vehicle at normal ride height. Not in the raised position.

Dynamic Balance: This normally refers to the balance condition of a wheel and tire assembly in motion.

Eccentric: See cam bolt.

Feather Edge Wear Pattern: An abnormal tread wear pattern where by one side of an individual tread rib is worn more than the other.

Flow Control Valve: Regulates flow output from the power steering pump. This valve is necessary because of the variations in engine RPM and a need for consistent steering ability in all ranges from idle to highway speeds.

Foot Pound: A unit of measurement used to describe torque force.

Four Wheel Steering: The ability of the rear wheels to aid in steering a vehicle for improved handling and driving characteristics.

Frame Angle: Used to describe a non-level frame.

Friction Ball Joint: Outer suspension pivot that does not support the weight of the vehicle.

Front Steer Rack & Pinion: Steering system located in front of spindle centerline.

Geometric Centerline: A line drawn between the midpoint of the front axle and the midpoint of the rear axle.

Horizontal: Parallel or level with the plane of the horizon.

Hub: The assembly that houses the bearings about which the wheel and tire assembly rotates.

Hydraulic Pump: A power driven device generating constant volume and pressure.

Idle Arm: An arm and lever assembly used to support and maintain a parallel position with a conventional steering system.

Included Angle: The sum of the angles camber and SAI.

Independent Suspension: A suspension system that provides an isolated mounting for each wheel to the chassis.

Individual Toe: The angle formed by a horizontal line drawn through the plane of one wheel versus a centerline.

Integral Power Assist: A power assist system where the control valve and all major hydraulic components are self-contained.

Intersect: The crossing point of two lines.

Jounce Travel: A suspension moving up through its travel.

Kinetic Balance: The balance condition of a rotating wheel related to force generated in a vertical plane.

King-Pin: A pin used to attach a spindle to an axle.

Lateral Run-Out: Side-to-side movement with a rotating wheel or tire.

Lead: A slight tendency for a vehicle to lead away from its directed course.

Linkage: A series of rods or levers used to transmit motion or force.

Load Carrying Ball Joint: Outer suspension pivot that supports the weight of the vehicle.

Load Range: A system used to describe the service or weight limitations of a tire.

MacPherson Strut: A suspension design where spindle, shock, and spring are all one assembly.

Memory Steer: A condition where the wheels, rather than returning to straight ahead, tend to remember and seek a previous position.

Millimeter: A unit of linear measurement. One millimeter is equivalent to 0.039 inches.

Minute: A unit of measurement used to describe an angle. One minute is equivalent to 1/60th of one degree.

Non-Integral Power Assist: A power assist system where the control valve and all major hydraulic components are not self-contained.

Offset: The lateral displacement of a wheel or axle in respect to a centerline.

Oscillate: A motion in two directions and at a specific frequency.

Out-of-Round: A wheel and tire irregularity in which one or both are not concentric with its axis of rotation.

Overinflation: Inflation pressure beyond what is recommended.

Oversteer: A characteristic in which a vehicle has a tendency to turn sharper than the driver intends.

Parallelogram Steering Linkage: A steering linkage design where if all pivot points are connected by lines, these lines would be parallel.

Passive Suspension: A suspension system which uses springs along with shock absorbers to allow compression (Jounce) and extension (Rebound).

Perpendicular: Being at right angles.

Pitman Arm: A steering component that provides interconnection between the steering gear sector shaft and the steering linkage.

Ply Rating: A method of rating tire strength; not necessarily indicative of the actual number of plies used.

Power Steering: A steering system which incorporates hydraulics to assist in the steering of the wheels.

Pre-load: A predetermined amount of load or force applied during assembly to prevent unwanted play during actual operation.

Pressure Relief Valve: Prevents power steering fluid pressure build up beyond a specified point. When fluid is at the maximum desired pressure the excess is returned to the pump reservoir.

Pull: The tendency for a vehicle to steer away from its directed course.

Rack & Pinion Steering Gear: A steering system designed that utilizes a pinion gear meshed with a rack gear to transmit steering forces to the spindles.

Radial Play: Any lateral movement of the wheel and tire assembly when inspecting a ball-joint or king-pin.

Radial Ply Tire: A tire construction type with alternating plies 90 degrees to the tire bead.

Radius: The distance from the center to the outer edge of a circle.

Rag Joint: A type of U joint constructed from a rubberized fabric type material.

Rear Steer Rack & Pinion: Steering system located in front of spindle centerline.

Rebound: A suspension moving down through its travel.

Recirculating Ball Steering Gear: A steering gear design that is made up of a worm shaft, ball nut, and two recirculating ball circuits.

Returnability: The tendency of the front wheels to return back to a straight ahead position.

Road Crown: The slope of a road from its center.

Road Feel: Necessary feedback transmitted from the road surface up to the steering wheel.

Road Isolation: The ability of a vehicle to better separate road irregularities from the driver and passengers.

Road Shock: An excessive amount of force transmitted from the road surface up to the steering wheel.

Scrub Radius: The radius formed between wheel centerline and steering axis projected load points at the road surface.

Setback: The angle formed between a centerline and a line perpendicular to the front axle.

Shim: Thin material of fiber or metallic makeup used to take up clearance between two parts.

Shimmy: A violent shake or oscillation of the front wheels transmitted up to the steering wheel.

Shock Absorber: A suspension component used to dampen spring oscillation.

Solid Axle Suspension: A suspension system consisting of one steel or aluminum I-beam extended the width of the vehicle.

Short Arm Long Arm (SALA): An independent suspension design incorporating unequal length control arm.

Spindle: A component on which a wheel and tire assembly is mounted and rotates.

Stability: The tendency of a vehicle to maintain a directed course.

Stabilizer Bar: A steel bar used to minimize body roll.

Steering Arms: A steering component which provides interconnection between the outer tie-rod and spindle.

Steering Axis Inclination: The angle formed by an imaginary line drawn through the steering axis versus vertical. Viewed from the front.

Steering Gear: A mechanical device used to convert the rotary motion at the steering wheel to a lateral motion.

Steering Geometry: See Alignment.

Steering Knuckle: A forged assembly which typically includes: the spindle, steering arm and steering axis pivot points.

Steering Shaft: A tube or rod which interconnects the steering wheel to the steering gear.

Steering Wheel Play: Any abnormal play or movement that does not result in movement at the front wheels.

Strut: Any support used between two parts.

Suspension: An assembly used to support weight, absorb and dampen shock, help maintain tire contact, and proper wheel to chassis relationship.

Suspension Height (Ride Height): The specified distance between one or more points on a vehicle to the road surface.

Thrust Angle: The angle formed by thrustline and geometric centerline.

Thrustline: Average rear toe added together and divided by two. The direction the rear rolls.

Tie Rod Assembly: The outer most assemblies on a parallelogram steering linkage. These assemblies are attached to the drag link and steering arms.

Tie Rod End: The ball and socket assembly of a tie rod.

Tie Rod Sleeve: A threaded tube that provides connection and adjustment of a tie rod assembly.

Tire Force Variation (Radial Force Variation): A tire irregularity in which there is a difference in radial stiffness about the circumference of the tire.

Tire Wear Pattern: The design developed on the tread surface from abnormal wear.

Toe: The comparison of a horizontal line drawn through both wheels of the same axle.

Turning Angle: The difference in the turning angle of the front wheels in a turn.

Torsion Bar: A spring steel bar used in place of a coil spring. Suspension is provided through its resistance to a twisting or torque effort.

Torque Steer: The effect that acceleration or deceleration has on the steering of the front wheels.

Tracking: The interrelated paths taken by the front and rear wheels.

Treadwidth: The dimension as measured between the centerlines of the wheels on the same axle.

Treadwear Indicators: Ridges molded between the ribs of the tread that visibly indicate a worn tire.

Underinflation: Air pressure below that which is specified.

Understeer: A characteristic in which a vehicle has a tendency to turn less than the driver intends.

Unit Body (Uni-Body): A design that incorporates both body and frame as a unit.

Vertical: Being exactly upright or plumb.

Vibration: To constantly oscillate at a specific frequency.

Waddle: The lateral movement of a vehicle usually caused by some type of tire or wheel imperfection.

Wander: The tendency of a vehicle to drift to either side of its directed course.

Wheel Base: The dimension as measured between the center of the front and rear axles.

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